NASA CONTRACTOR REPORT

(NASA-CR-171531) MICROGRAVITY SILICON ZONING INVESTIGATION Final Report, 15 Jul. 1982 - 15 Jul. 1985 (Westech Systems, Inc.) 88 p HC A05/MF A01 CSCL 22A

N85-31073

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G3/12 21864

NASA CR-171531

MICROGRAVITY SILICON ZONING INVESTIGATION

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Final Report

May 15, 1985

Prepared for

NASA - Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA CR-171531		

4. TITLE AND SUBTITLE
Microgravity Silicon Zoning Investigation

5. REPORT DATE
May 15, 1985

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Edward L. Kern/Gerald L. Gill, Jr.

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Westech Systems, Inc.
3502 E. Atlanta Avenue
Phoenix, AZ 85040

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.
NAS8-34920

12. SPONSORING AGENCY NAME AND ADDRESS
National Aeronautics and Space Administration

Washington, DC 20546

13. TYPE OF REPORT & PERIOD COVERED
Final Report
7-15-82 to 5-15-85
Contractor Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Technical Manager: I C. Yates, Marshall Space Flight Center, AL 35812
Spacelab Payload Project Office

16. ABSTRACT
The objectives of this effort were to experimentally investigate the flow instabilities in floating zones of silicon and to define methods for investigation of these instabilities in microgravity. The investigation involved three principal tasks: characterization of the float zone in small diameter rods; investigation of melt flow instabilities in circular melts in silicon disks; and the development of a prototype of an apparatus that could be used in near term space experiments to investigate flow instabilities in a molten zone. Experiments in a resistance heated zoner with 4 to 7 mm diameter silicon rods have shown that the critical Marangoni number is about 1480 compared to a predicted value of 14 indicative that viable space experiments might be performed. The disk geometry proved to be not suitable for space experiments since there was no strong evidence of melt flow instabilities in ground-based experiments. The prototype float zone apparatus was built and tested and specifications prepared for a flight zoner should a decision be reached to proceed with a space flight experimental investigation.

17. KEY WORDS
Float zone; silicon; single crystal growth; microgravity; materials processing in space

18. DISTRIBUTION STATEMENT
UNCLASSIFIED - UNLIMITED

James A. Downey III
Manager, Spacelab Payload Project Office

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
UNCLASSIFIED	UNCLASSIFIED	88	NTIS

SUMMARY

This is the final report on Contract NAS8-34920, "Microgravity Silicon Zoning Investigation," which has a second year contract period from 5 December 1983 to 17 December 1984. This contract was performed for NASA's George C. Marshall Space Flight Center and was monitored by Mr. I. C. Yates. The contract was performed by Westech Systems, Inc. of Phoenix, Arizona, with Gerald Gill, President, as Program Manager. Principal Investigator was Dr. Edward L. Kern, of Edward Kern and Associates, Solana Beach, California.

The work on the contract was divided into three tasks: Task 1, "Characteristics of the Float Zone in Small Diameter Rods"; Task 2, "Silicon Slice Zoning"; and Task 3, "Prototype Float Zone Apparatus". An Interim Report, submitted to NASA on July 15, 1984 reported on the scientific results on Tasks 1 and 2 up to that date and those results will be summarized in this report.

The Thin Rod Zoner apparatus, built and operated in the previous contract period, was modified and a series of new platinum wire hot-wall heaters designed, constructed, and characterized. Silicon rods of 4 to 7mm diameter had floating molten zones of up to 10mm length, utilizing 200 watts power. These zones were solidified at varying rates and analyzed for striations which indicated instable melt flows. No striations were observed, which would indicate a critical Marangoni number (if bouyancy flow is ignored for small melts) above 1180, compared to a predicted value of 14 from a simple model. If this number is also applicable to microgravity conditions, silicon crystals of practical sizes for semiconductor arrays could be grown in space without the electrical property inhomogeneities of striations.

A Silicon Slice Zoner was constructed and circular melts formed and regrown at controlled rates. As predicted by some theories, no strong evidence of melt flow instabilities

was seen. Instabilities, probably due to fluid flow at time of solidification, led to surface reliefs of fluted and platelet configurations.

The hot wall zoner was redesigned for better growth experimental conditions, being designed as a flight hardware prototype. This Prototype Float Zone Apparatus was constructed and tested in zoning. Technical specifications for zoning silicon experimentally and for the zoner hardware are included.

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I. CHARACTERIZATION OF THE FLOAT ZONE IN SMALL DIAMETER RODS

The development of earlier space flights, with experiments on material characterization, and now the Space Shuttle, provides the opportunity to look for possible differences in processing materials in the space environment. The unique feature in space experimentation, which cannot be obtained on earth, is the very reduced gravity (microgravity). In melts, the absence of a significant gravity influence will minimize bouyancy-driven flows, which lead to inhomogeneities in many crystals grown on earth. Microgravity will also allow the characterization of Marangoni flows, driven by surface tension differences within a melt. The characteristics of the flow have been modeled for simplified melt systems, but work is only starting[18] which will approximate a real zone in materials of interest. Experimental determination in microgravity is information we need to understand the growth of materials in space, as well as to more fully understand the role of Marangoni flow in earth growth processes.

Silicon was selected as the primary experimental material because it is a very important high technology material for both industry and the government, because it is better characterized than most other high growth temperature materials, and because inhomogeneities caused by earth grown melt flows limit the performance of important devices. The former NASA Float Zone Working Group indicated that a high temperature melt (silicon) could not be adequately modeled by a low temperature melt[17].

The influence of the absence of bouyancy flows on the grown crystal and the characterization of Marangoni flows will be used for several purposes:

1) Predict what improvements, if any, can be made in crystals grown in microgravity conditions, as compared to crystals grown on earth.

2) Predict the size limits for which improvements can be expected.
3) More fully understand the relative roles of bouyancy and Marangoni flows in earthbound growth methods, such as float zone and Czochralski crystal growth of silicon and other crystals.

Microgravity zoning will also provide for growth of crystals whose growth is not possible on earth. Most Si-Ge alloy compositions cannot be grown now due to gravity separation of heavy components, which will also be true for certain III-V quaternary alloy [17]. Inadequate surface tension does not allow many heavy metals to be grown by float zone (Tellurium, for example), and does not allow growth of practical sizes by float zoning of, for instance, GaAs. Since float zoning is a containerless process capable of growing very high purity and highly perfect crystallography[19], this could be important for the development of future high technology semiconductor devices, as well as materials for other applications.

A Thin Rod Zoner was designed and constructed during the first year of this contract and was described in the first annual report on this contract.[1] The objectives in building the new zoner were:

1) To be able to carry out float zoning experiments on the Space Shuttle within the power, cooling, and emi (electromagnetic interference) limits of the Shuttle (e.g., the carrier in the bay [MSL]).
2) Eliminate the periodic (rotational) meltback striations found in crystals float-zoned with r.f. power (due to the coil slot).
3) Minimize the temperature gradients in the melt to minimize Marangoni flow and to maximize uniformity of impurities (including dopants) and point defects (swirl).

As was shown in the last contract period,[1] this is best accomplished using resistance-heated, hot-wall heating elements. Since this is the first time that float zoning silicon has been tried using a tailored hot-wall heater, all aspects of the design and operation are new. Additional complications are introduced by working in a weightless environment, such as designing chucks (to hold the silicon rods) such that they can work without the utilization of gravity.

A. GROWTH OF SMALL DIAMETER SILICON CRYSTALS

Melting and regrowth of silicon crystals was done in the cylindrical configuration by both the Thin Rod Zoner model described in the previous contract period[3], and the model constructed in this contract period and described in Section IV of this report. Both zoners heat the silicon with a thermally-profiled, resistance-heated wall and both are designed to zone diameters up to 7mm.

The thermal profile of the heater must be designed such that a molten zone is melted, having these characteristics:

1) The zone length is as long as desired, but not too long to not be supported by surface tension (for earth, g=1 growth).
2) The thermal axial gradients are minimized.

A series of variable-winding-density, two-layer coils were designed and tested, using Pt-10% Rh wire. The thermal profiles of these are given in references 1 and 3 and Section IV A below. A quartz liner is used inside the alumina heater core to protect the heater from melt spills, and a new quartz liner is used each time to provide the same thermal conditions each time.

Using the new heater design and the quartz liner, a series of melting experiments were run. A static zone, being melted and refrozen without moving the molten zone through the rod, is initially done to characterize the molten zone itself and freezing characteristics, without the complications of advancing the melting an' ̄reezing lines (supplying the heat of melting and extracting the heat of freezing) and axial and rotational sp·ed effects. Table 1 outlines the series of runs. The observations on these regrown crystals are presented in the next section.

The starting silicon thin rods for these experiments have been standaɪd thin rods, normally used for deposition of polycrystal silicon in decomposition reactions, with diameters between 4 and 7mm. They are pulled at a fast speed (16-20mm/min.), are straight, and have very uniform diameters, as is required for this zoner. These were pulled on a commercial thin rod puller (made by and operated at Westech Systems). These rods are usually not single crystal, since polycrystal rods are preferred for the silicon deposition. Since no seeding-in procedure is being used, the crystal regrowth is not expected to be single crystal. The diameter is grown at 4-7mm, as desired. The rods are cut 18-inch long and each end is ground in a lathe to have a uniform diameter that will fit into the end chucks of the zoner.

Analysis of the melt shape and characteristics of the regrown crystal is done by striation etching the cross section. The author developed this etch to sharply delineate any slight change in lattice spacings (through a change in chemical activity) and any crystallographic defects.[20] The detailed etching conditions are given in Reference 4. The silicon rod is sliced axially with a diamond saw, lapped, chemically polished, and then striation-etched. The etched crystal is observed by Nomarski (phase interference contrast) microscopy.

The power required to melt silicon rods 5.5 to 6mm diameter is 173 watts of heater design number II[1] and 200 watts for heater design number III (Section IV). These have a larger diameter alumina heater core and a quartz liner, as compared to the smaller core and no liner requiring 88 watts[3]. The heater core is 1501°C, compared to approximately 1430°C[3], the melting point of silicon.

TABLE 1. SILICON THIN ROD ZONE MELTING EXPERIMENTS

Rod #	Diameter (inches)	Diameter (cm)	Heater Temp. (°C)	Power (Watts) Primary	Power (Watts) Secondary	Power (Watts) Total	Molten Zone Length (in.)	Remarks
1	.18	.45	1516	143.0	31.3	174.3	.40	Melted thru
2	.265	.662	1528	158.9	25.2	184.1	.33	Melted thru quartz liner devitrifying
4	.25	.62	1432	164.6	30.0	194.6	.385	Melted thru
5	.25	.62	1527	159.7	22.0	181.7	.65	Quartz liner degrading new liner
7	.220	.55	1500	155.3	18.32	173.6	.40	Melted thru
8	.220	.55	1501.5	147.24	17.02	164.4	.38	Melted thru
9	.210	.52	1501	153.3	16.0	169.3	.40	Melted thru and refroze in situ
11	.225	.56	1501.5	145.32	16.11	161.4	.37	Melted thru

NOTE: Temperature is read off a thermocouple placed on the alumina core of the heater. This thermocouple is embedded in alumina cement. The thermocouple readout unit is calibrated to within 0.5°C.
Power is given for the primary (inner) winding and secondary (outer) winding.

The power required for melting is well within the power available on the Shuttle carrier (400 watts, including electronic controls)--and more could be available by careful time-lining.

The maximum melt height (or volume) is limited by the surface tension of the silicon. The levitation normally available from the r.f. power in r.f. heating is not available with hot-wall zoning. Too much melt leads to a sagging of the melt which contacts the quartz liner or spills down the side of the bottom rod. This has happened with melts as thin as 5.4mm (0.215 inches) high, but in this case might have been due to vibrations or other mechanical disturbance. Melts above 1.0cm (0.4 inches) cannot be contained, such as a 1.5cm length of 7mm diameter rod. The limit of 1.0cm long for 6mm diameter suggests a surface tension considerably less than Hardy's value of 885 mJ/m^2 (8) for a clean silicon surface. This suggests an oxygen contaminated surface, which is not unexpected. The melt surface does not have a crust on it, which would indicate a gross oxygen source, but often has a colored thin oxide layer. Outgassing of the furnace structure is difficult to completely do and the argon stream will have several ppm, even without leaky fittings, etc.

B. CHARACTERISTICS OF GROWN CRYSTALS

The initial growth experiments start with the grown silicon thin rod and melt partly or all the way through the cross section, with the crystal being regrown by cooling at a controlled rate. The molten zone starts as a shallow molten ring into the rod. Figure 1 shows the melt throughout the cross section, with the furnace temperature of 1500-1501°C being held for a short heat soak (up to 3 minutes) and the slow regrowth done at a cool down rate of about 0.1mm/minute. The last-to-freeze interface is a shallow concave surface with a radius of curvature of 8.8mm for a 2.6mm radius rod.

This shallow concave interface is an important goal in our furnace design and confirms the suitability of the furnace design and zoning parameters. The regrowth was so gradual that the crystallography of the unmelted rod is continued in the regrown crystal without changes in the crystal direction or defects (i.e., epitaxial growth).

Striations are usually not observed in the regrown crystals, especially at the surface, where Marangoni flow would affect the melt flow and cause instabilities. The few striations that were observed are in the interior of the regrown crystal and do not extend to the surface. Some are thought to be flow instabilities in the fast growth of small interior grains and are not associated with surface flows.

Striations due to a combination of bouyancy and Marangoni flows are not observed in the carefully regrown thin rods, in contrast to larger diameter float zoned crystals grown at g=1[4] or in SpaceLab[9] in microgravity. The objective of the design of this Thin Rod Grower was to tailor the heater profile such that axial and radial gradients were minimized, while a zone of controlled length is melted, thus minimizing Marangoni flow to the extent of avoiding turbulent (instability) flow. This appears to have been accomplished.

C. INFRARED MICROSCOPY OF SILICON MELTS

Instability striations due to a possible combination of bouyancy and Marangoni flows is always observed in larger diameter silicon crystals grown by float zoning. These were characterized at 25mm diameter in an earlier program[4]. The previous contract period[3] attempted to record these thermal fluctuations with a thermocouple in the solid near the melt or in the melt. The inability to passivate the thermocouples led to fast alloying of the thermocouple junction and very erratic readings.

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Figure 1. Melted Through Section of Silicon Thin Rod.

5.2mm diameter silicon thin rod (at left of samples) was completely melted through and refrozen. The curved line across the diameter is the (last-t - freeze) solid-melt interface. The melt extended to the shoulder on the right side.

An infrared microscope with small area resolution and fast speed response should be able to see small variations on the surface of the silicon melt. A Barnes model RM-2A infrared microscope was obtained through NASA and installed on the NASA Breadboard (r.f.) zoner. Figure 2 shows the zoner and Figure 3 shows the I.R. microscope mounted next to the right side window port of the zoner. Figure 4 shows the schematic of the light path from the molten zone to the I.R. microscope. A new base, with an x-y table, was constructed for the microscope to allow for precise positioning and to get the microscope within the focal length of the melt surface.

Since the r.f. work coil obscures most of the length of the molten zone when viewed perpendicular to the rod axis, an angled split image is used. This is done using four front surface mirrors, which then recombine the top and bottom portions of the view at the microscope. The entire obscuration of the coil can be eliminated. Figure 5 shows the means of adjusting the bottom and top mirrors with vertical adjustments (shown) and mirror rotation.

The microscope resolving spot size was larger than desired, so a 1/32 inch hole in an aluminum plate was used as an aperture, resulting in an observed spot size of .05mm (0.020 inches).

Recording the emission of the sample while zoning picks up several features. Each rotation usually gives one big peak and two smaller peaks, indicating the growth lines and three-fold geometry as seen by the eye. On top of this rotation structure (or if the rotation is stopped so there is no structure), is seen an oscillation with a period of 1.5-2.0 seconds of very small amplitude. From our earlier report[4], a striation frequency of 0.23-1.5 seconds is observed for a 25mm diameter melt, which this is. This does indicate that the observed oscillation in the infrared is probably the same as causes the structural striations that are observed. Since the crystal was not traversed during these studies, the striation pattern cannot be observed.

The magnitude of the temperature excursion can only be roughly approximated, both because the amplitude changes on the recorder are very small and because the observation of the I.R. emission at an angle to the melt surface (due to the optics shown in Figure 4) will provide different amplitudes (at the same temperature) due to the cosine nature of the emission of light. It is thus roughly estimated that the temperature excursions are less than $2^{\circ}C$ (installing an iris to give a small spot size eliminated the earlier calibration, thus making estimates more difficult). These correspond to striations observed by striation etching of the sample. Occasional thermal spikes of much larger magnitude (maybe 10 or more degrees) are seen as the crystal is being grown.

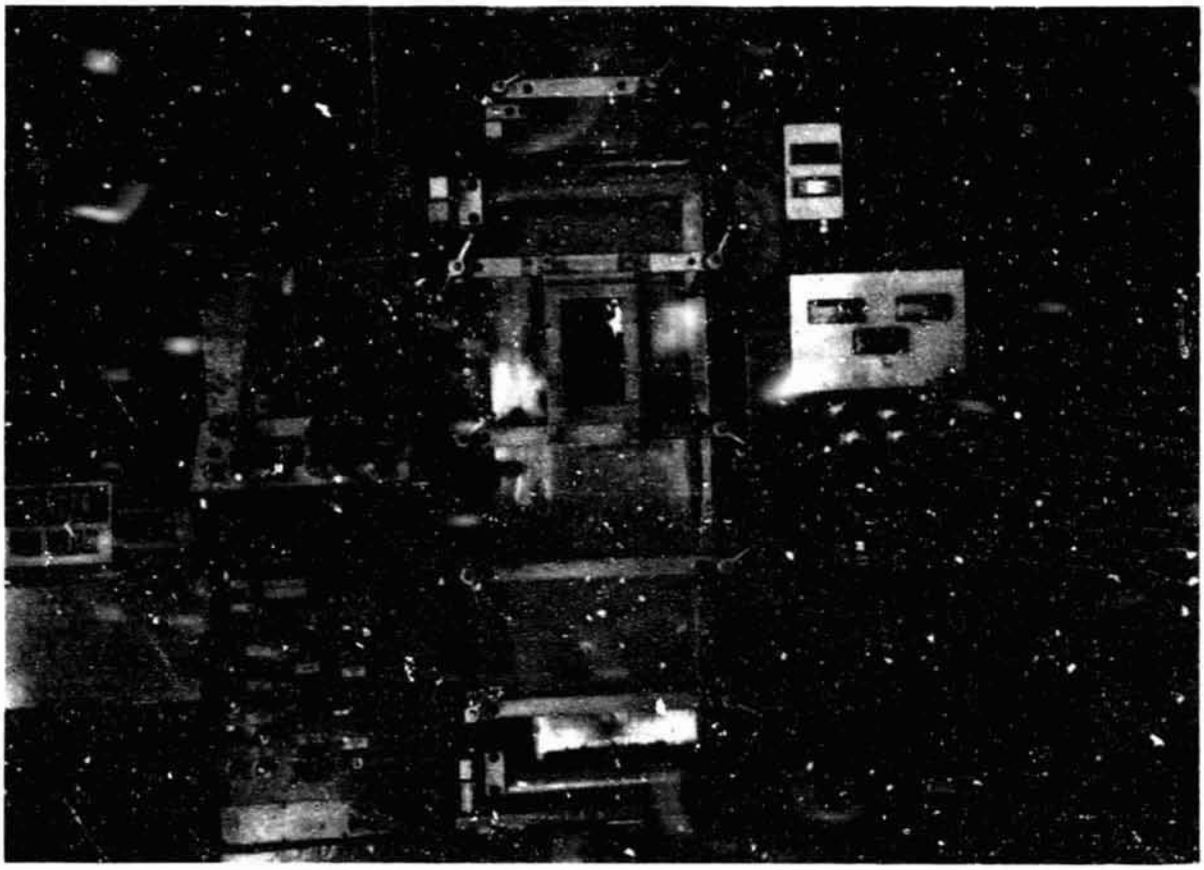

Figure 2. NASA Breadboard Zoner

This vacuum/gas zoner is used to study silicon melts at larger diameters, using r.f. powered coils.

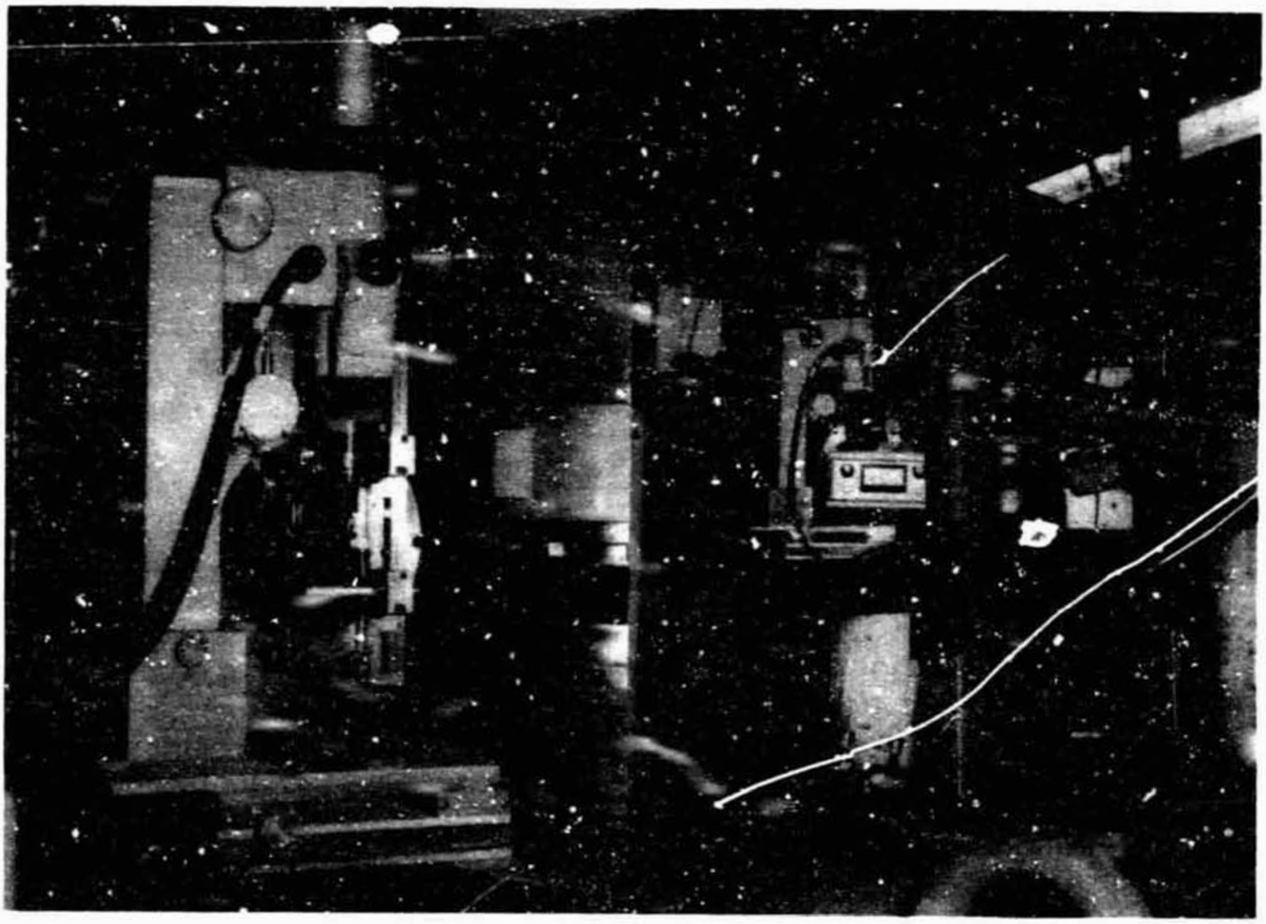

Figure 3. Infrared Microscope Mounted on Breadboard Zoner

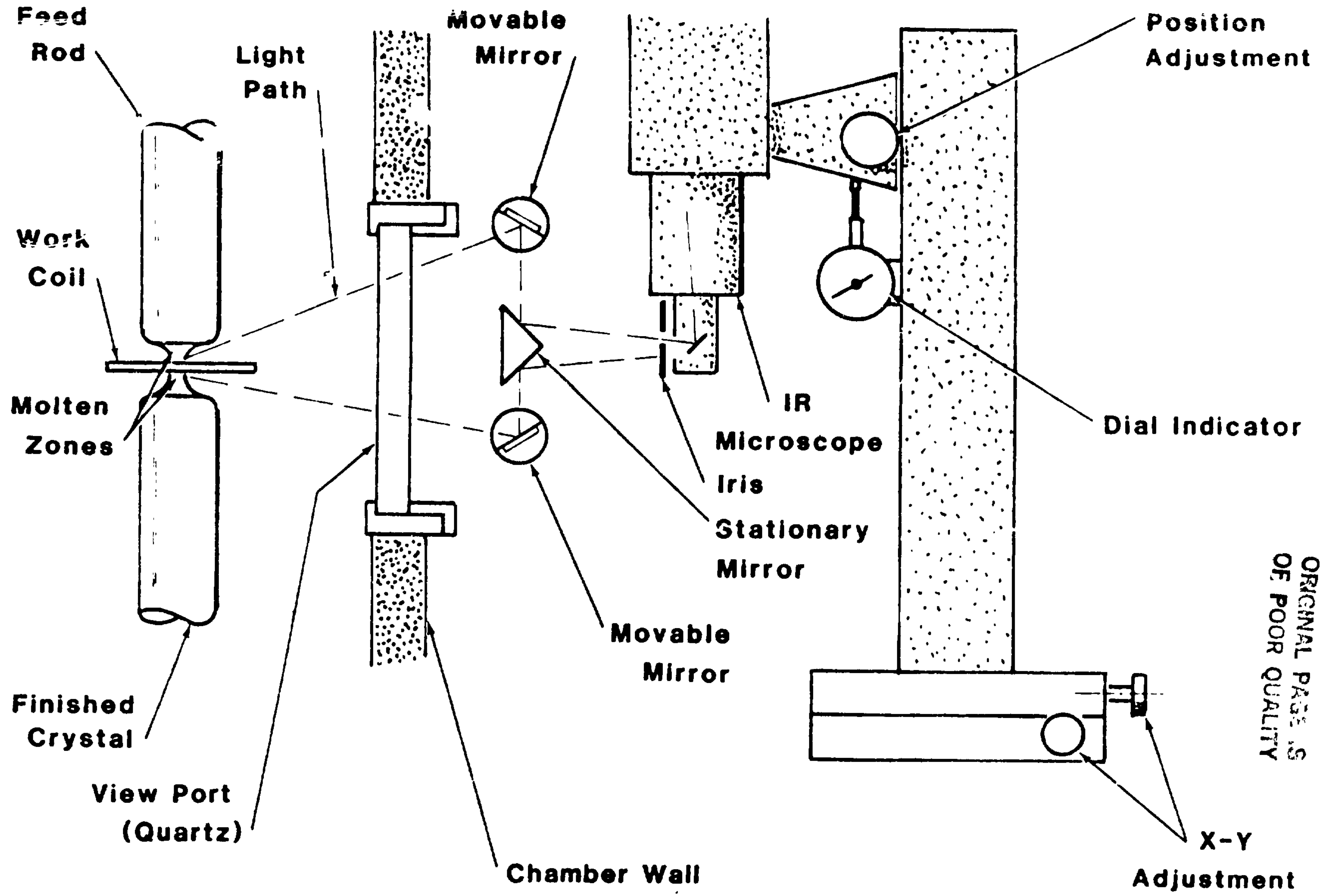

Figure 4. **Light Path Schematic**

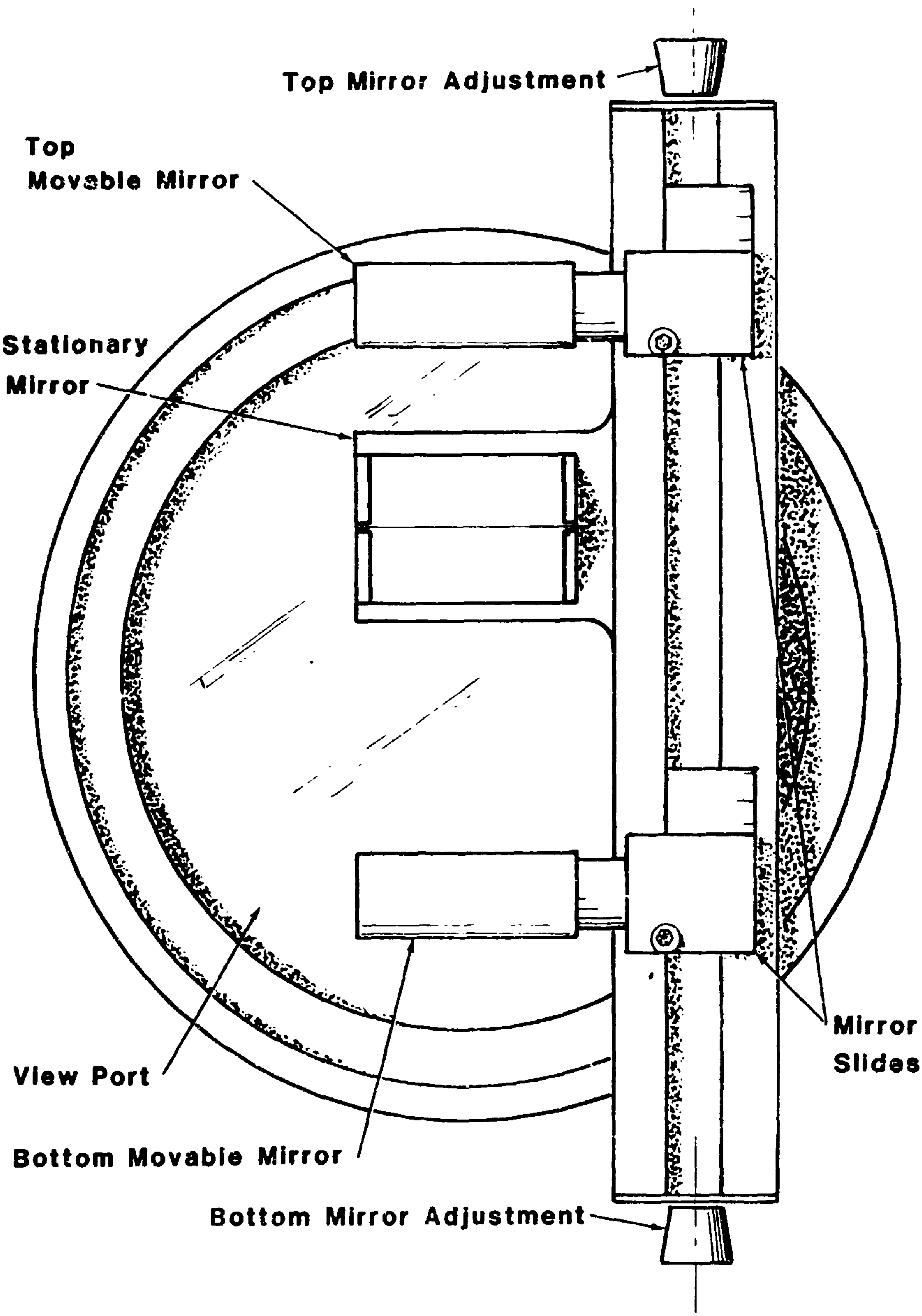

Figure 5. **Mirror Mounting on View Port**

II. SILICON SLICE ZONING

An experimental characterization of the Marangoni flows in silicon melts is needed to determine its role in affecting crystals grown from the melt in microgravity and to separate the roles of Marangoni and bouyancy flows in earthbound crystal growth. While this will eventually be most clearly done by experimentation on the Space Shuttle and Space Station, its role needs to be defined now to a) guide the planning of microgravity experiments, and b) to correlate with and help to define theoretical models now being studied. The latter reason was highlighted by this contract's interim report, which indicated that the critical Marangoni number (M_c) for a rod geometry was estimated to be >436[1], much higher than Xu and Davis' simple model M_c of 14.7[16].

One method of attempting to separate out the effects of Marangoni and bouyancy melt convection contributions is to go to a very long aspect ratio melt, which is thin in the direction parallel to gravity forces, and which has a high surface area. The melting of thin silicon slices was suggested by the former Float Zone Working Group[2]. Initial experiments were done by melting the center of a silicon slice with an electron beam in vacuum[3]. Striations were observed only in interior grains of rapidly solidified slices, but not at the melt surface where Marangoni flow should dominate. Problems with the electron beam melting led to designing and building the "Slice Zoner" described in the following pages.

A. SILICON SLICE ZONER

A silicon slice zoner was designed and developed for the purpose of melting the center portion of a silicon slice and resolidifying at a controlled rate. Controlling the diameter and growth rate will provide for different aspect ratios and temperature gradients, to give a range of Marangoni numbers and critical parameters (i.e., those of W. N. Gill). The feasibility of using elliptically focused light heaters was studied at the Space Science Laboratory at Marshall Space Flight Center during the previous contract period[3], which led to the following design.

The goal of this equipment design was to provide a simple and relatively inexpensive system that will control the heating and regrowth rate, melt diameter and the gaseous atmosphere. Figure 6 shows the unit, which utilizes a) a used vacuum system, b) a chamber machined from aluminum, c) inexpensive elliptically focused heaters top and bottom, and d) either manual or semiautomatic heater controls.

The chamber cross section, depicting the sample holding configuration, is shown in Figure 7. The quartz windows are recessed into the vacuum chamber to allow closer coupling of light to the silicon slice. The aluminum recessing rings are conductively cooled by the chamber, which is water-cooled. Viton rubber vacuum gaskets are needed to withstand the high temperatures. A quartz ring, resting on the bottom quartz window, is used when a minimum of heat extraction from the slice is desired. This is replaced by a water-cooled copper ring, attached to the chamber removable end plate, when more heat extraction is desired for higher temperature gradients (see Figure 8). The latter takes considerably more power and leads to fast degradation of the quartz windows and is shown schematically in Figure 9.

Key features of the components in Figure 7 are:

quartz windows	:	4.375 inch diameter x .375, or .187 inch thick
spacing a	:	.296 inch
spacing b	:	.296 inch
quartz ring	:	1.5 inch outer diameter x 2 mm wall
Viton gasket	:	0.060 inch thick

Figure 9 shows a schematic of the vacuum chamber and the elliptical heaters. The heaters are low cost, commercially available heaters from Research Incorporated. While the spun aluminum reflectors are not quite as efficient in reflecting compared to more expensive custom generated reflectors, their cost and ease of re-working was cost-efficient in the developing of this equipment. The elliptical heater specifications are:

Manufacturer	:	Research Incorporated Model #5530
Size	:	1000 W 120VAC
Tungsten-halogen lamps	:	Sylvania 1000Z/3Cl (1000W at 120V)

Control and reproducibility of results requires a programmed heater control unit. Initial testing of the system and experimentation was done by using manual ramping of a variac on each heater. This also defined the control parameters for the controller. The controller is shown in Figure 10. An analog time ramping and hold design was selected for simplicity of hardware and operation. The selected parameters are:

ramp up	:	100 sec. to 2.7 hours
hold at maximum temperature	:	1-15 min.
maximum power	:	>2300 watts for two lamps (limited by boost transformers)
ramp down	:	100 sec. - 2.7 hrs. - two ramping speeds
power switchover between two down ramps:		set point 250 (600 watts) to 300 (.700 watts) typical
power cutoff	:	set point 100, 250 watts--typical

The schematic of the control circuit is shown in Figure 11.

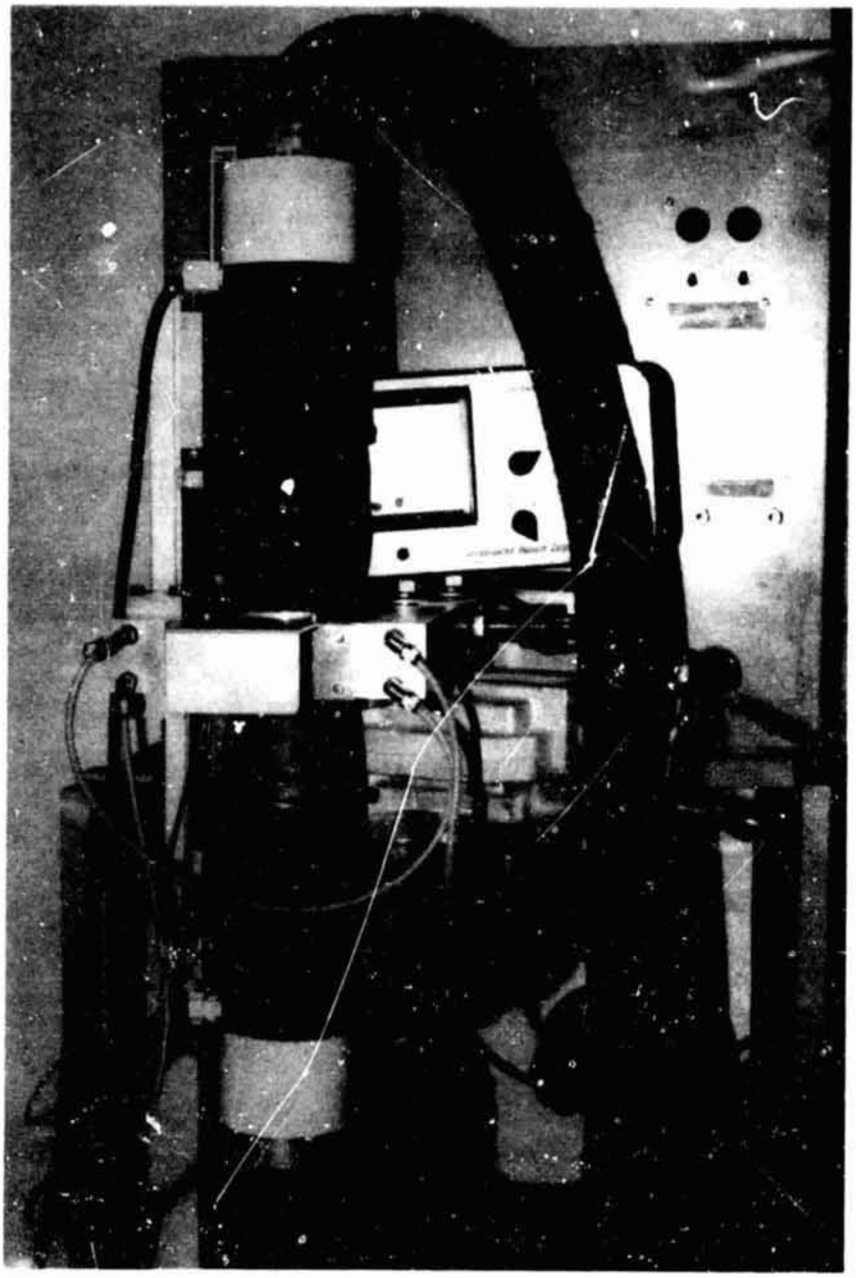

Figure 6. Silicon Slice Zoner.

The elliptical heaters are seen above and below the aluminum chamber. The chamber can be operated with an argon pressure atmosphere, or partial pressure, or high vacuum. The sample holding and cooling tubes and thermocouple leads are behind the metal shield in front. The chamber is water cooled. The lamps are air cooled (hoses).

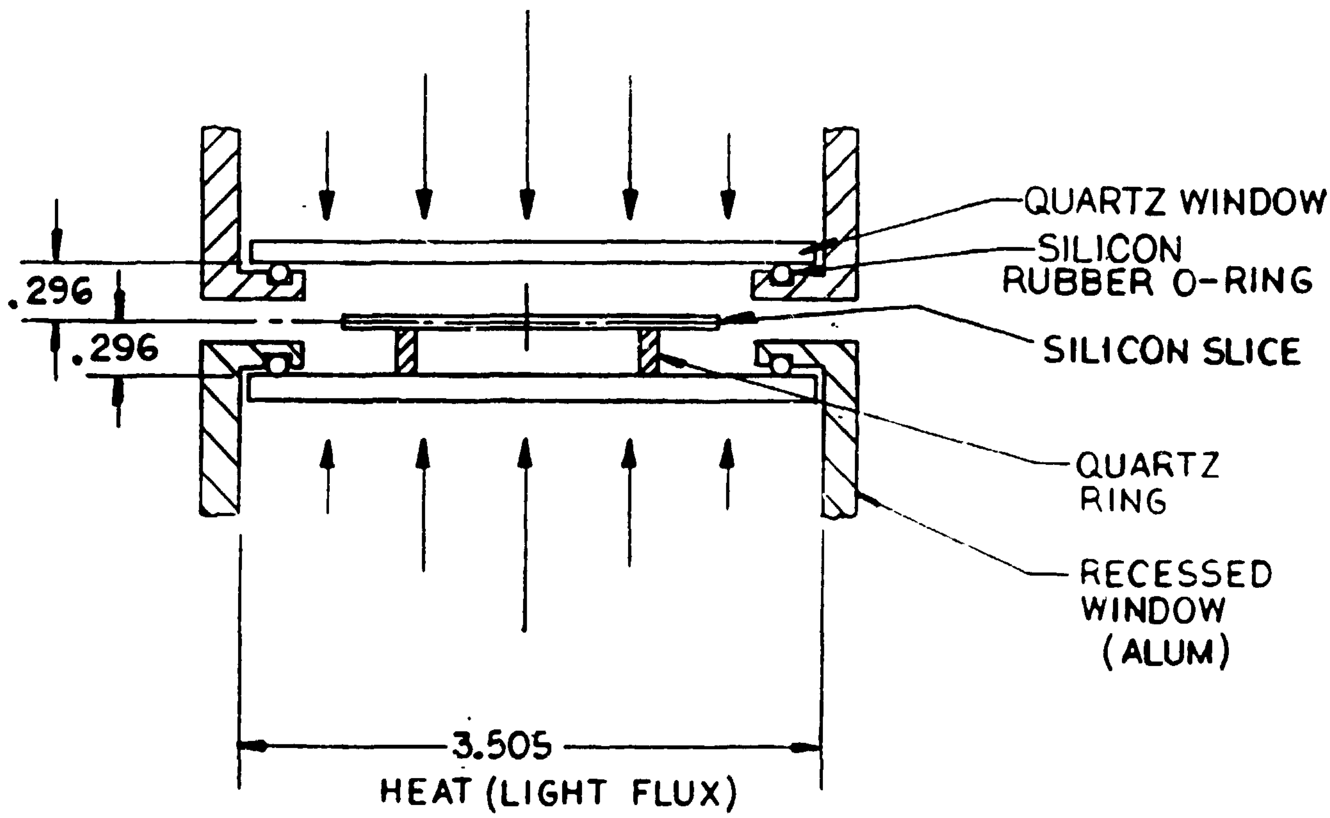

Figure 7. Silicon Slice Zoner Cross-Section

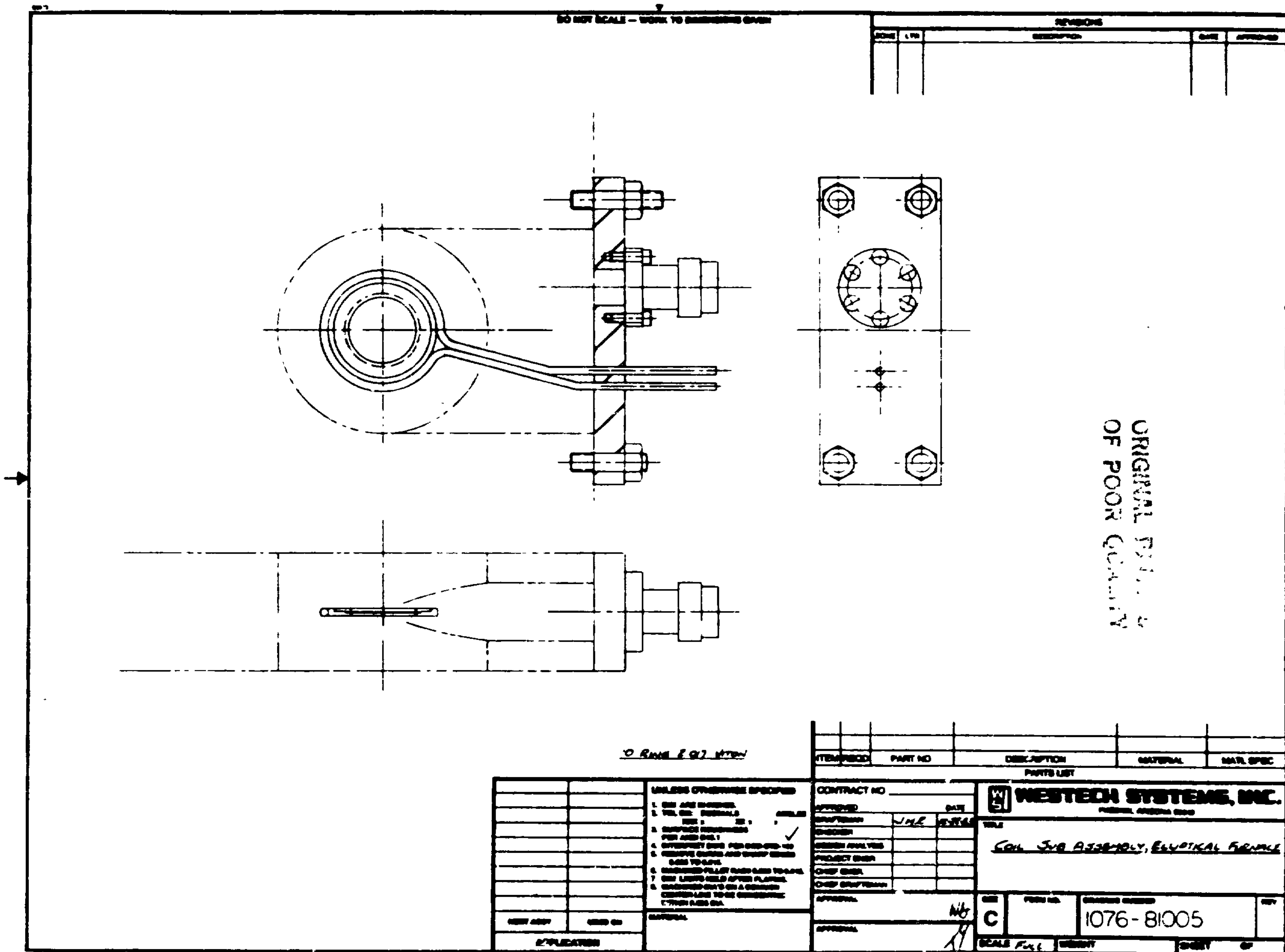

Figure 8. Coil Sub Assembly, Elliptical Furnace

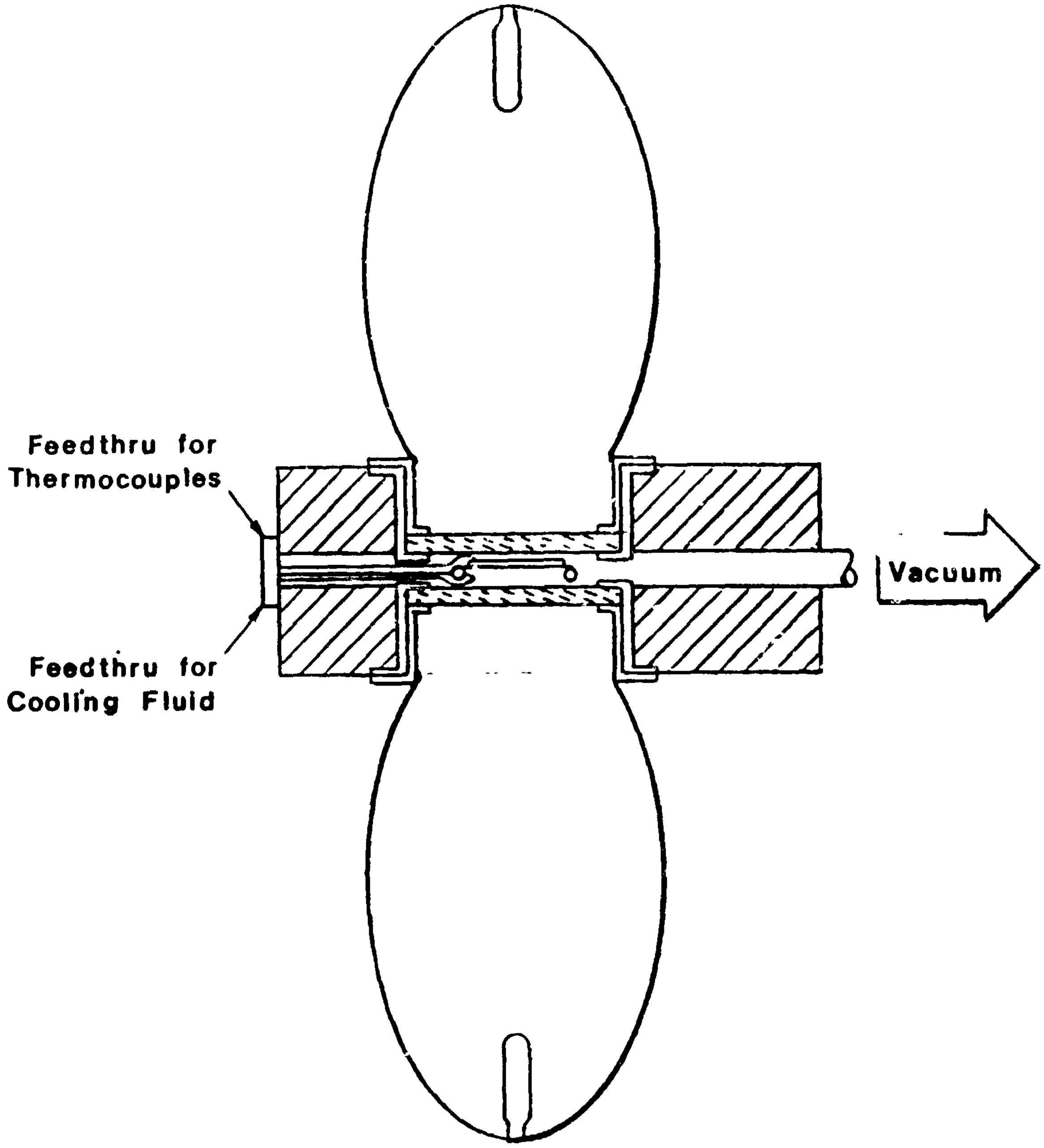

Figure 9. **Section through Furnace**

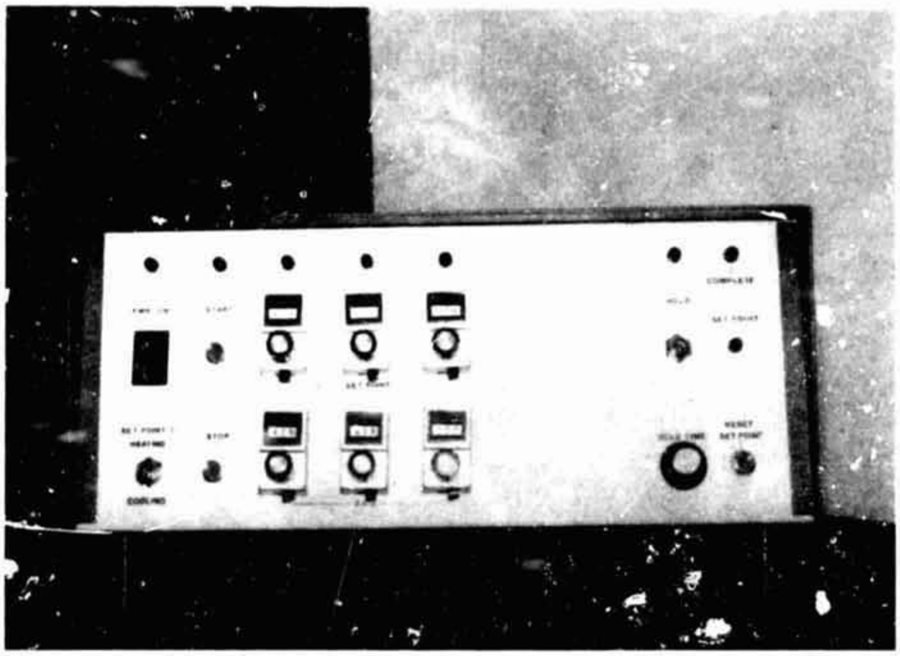

Figure 10. Slice Zoner Programmed Controller

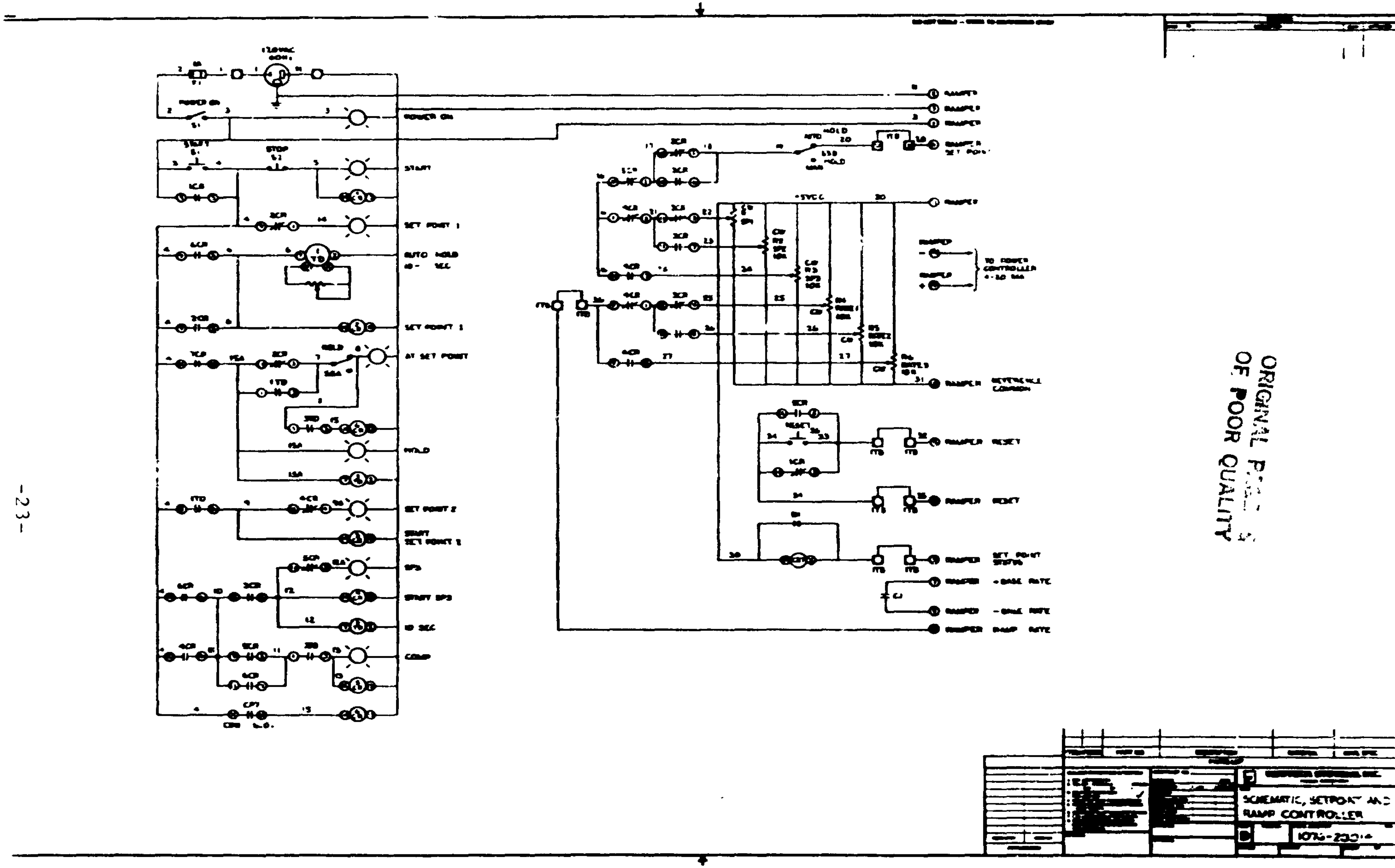

Figure 11. Circuit Schematic for Slice Zoner Programmed Controller (Figure 10).

The heater controller provides the control signal to the power controller circuit, which is shown in Figure 12. To obtain the extent of slice melting desired, the tungsten-halogen lamps must be run at voltates higher than 110 v.a.c. and power boost transformers are necessary. The range of power going into the heater lamps is included in Table 2 in the following section.

B. SLICE ZONING

Silicon slices of two inch diameter and thickness of 0.30 to 0.65mm (0.012 to 0.026 inches) are zoned with the Slice Zoner. The slices are heated by slowly increasing the lamp intensities, both lamps being powered equally, either manually or with the electronically programmed heater controller. Slow heating is needed to avoid shocking and cracking the silicon slices. The power needed to obtain a given diameter melt is determined from previous runs, since the slice cannot be observed when being heated. This is because the light intensity is very high (1100 watts from each lamp in a confined area), and because a viewing port would lead to a light loss and nonsymmetric heating. The maximum power is held for a period (3 minutes) previously determined to be sufficient for a steady state to be attained for the power setting. Holding for longer periods of time leads to unnecessary deterioration of the quartz windows.

The crystal growth rate is determined by the speed of ramping down the power. A constant growth rate would entail decreasing the light intensity per unit area of a decreasing circle. Doing this precisely would involve a computer program and taking into account the heat flows in the slice and focused light intensity profiles, which would take considerable time. For samples 23 to 28 in Table 2, the power per unit area (power into the lamps) of the entire slice was reduced linearly by using 10 equally timed steps, manually. The heater controlled

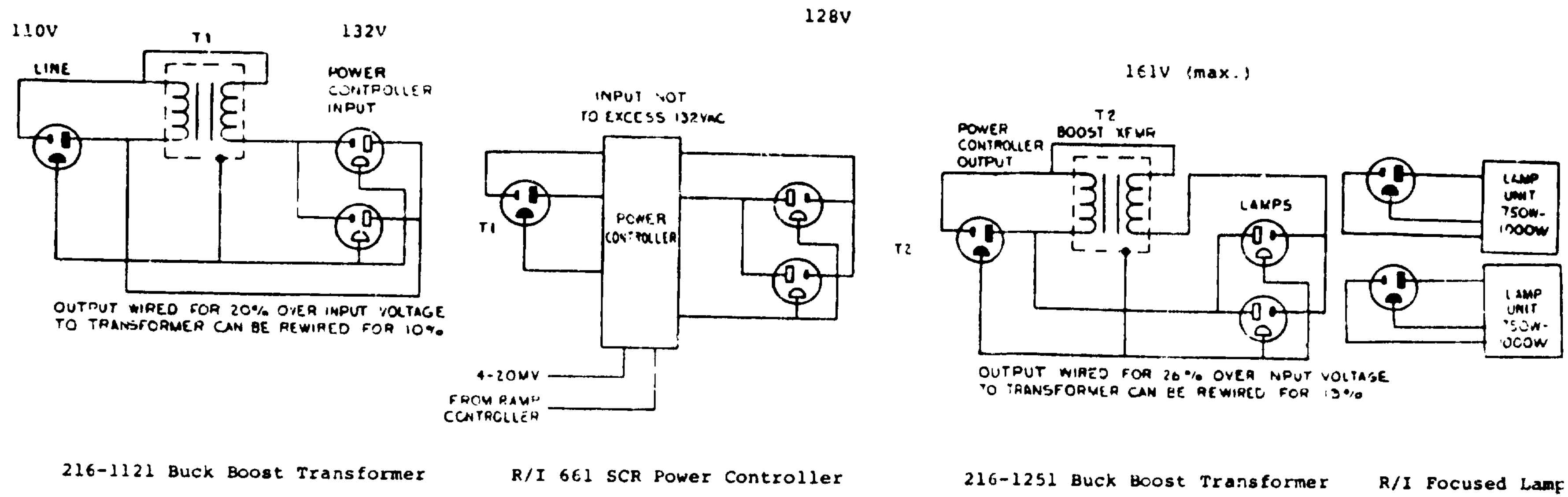

Figure 12. Circuit Diagram of Slice Zoner Power Controller

TABLE 2. SILICON SLICE ZONING EXPERIMENTS

REF.	MELT DIAMETER (INCHES)	POWER REQUIRED (WATTS)	WAFER THICKNESS (INCHES)	WAFER THICKNESS (MM)	VACUUM	ATMOSPHERE PRESSURE W/ARGON FLOW P.S.I.	ATMOSPHERE PRESSURE W/ARGON FLOW CC/MIN.	TIME AT MAXIMUM TEMPERATURE	TIME TO FREEZE	GROWTH RATE (APPROX.)
A	.220	1536	.025	.625		3.0	47	3 min.	20 sec.	8mm/min.
B	.150	1426	.025	.625		3.0	47	3 min.	40 sec.	3mm/min.
C_1	.015	1320	.012	.30	15m/torr			3 min.	fast	fast
C_2	.115	1320	.012	.30		3.0	47	3 min.	1 min.	1.5mm/min.
1	.300	2079	.020	.50	37m/torr		140	2 min.	fast	fast
2	.287	2212	.020	.50	1 torr		105	2 min.	40 sec.	5mm/min.
3	.230	2212	.020	.50	$2.4x10^{-5}$			2 min.		
6	.190	1700est.	.020	.50		3.0	12	5 min.	40 sec.	3.5mm/min.
8	.350	2260	.026	.65		0.3	12	3 min.	30 sec.	9mm/min.
9	.350	2260	.012	.30		0.3	12	2 min.	40 sec.	7mm/min.
10	.250	2260	.012	.30		0.3	12	2 min.	60 sec.	3mm/min.
11	.250	2260	.012	.30		0.3	12	2 min.	40 sec.	5mm/min.
12	.430	2260	.012	.30		0.3	12	2 min.	30 sec.	10mm/min.
16	.380	2111	.025	.025		0.3	12	30 sec.	fast	fast
17	.275	2023[1]	.025	.625		0.3	12	2 min.	4 min.	1mm/min.
18	.365	2237	.024	.60		0.3	43	2 min.	2 min.	2.3mm/min.
19	.500	2237	.025	.625		0.3	47	2.5 min.	fast[3]	fast(100mm/min)[4]
20	.340	2237	.025	.625	$1x10^{-5}$			2 min.	20 sec.	12mm/min.
21	.450	2237	.025	.625		3.0	47	2 min.	fast	fast
22	.480	2237	.025	.625		3.0	47	3 min.	1 min.	6mm/min.
23[2]	.480	2240	.025	.625		0.33	50	2.5 min.	5 sec.	72mm/min.[5]
24	.440	2240	.025	.625		0.33	50	2.5 min.	10 sec.	33mm/min.[5]
25	.475	2240	.025	.625		0.33	50	2.5 min.	20 sec.	17.8mm/min.[5]
26	.380	2240	.025	.625		0.33	50	2.5 min.	40 sec.	7.1mm/min.[5]
27	.435	2240	.025	.625		0.33	50	2.5 min.	80 sec.	[illegible].1mm/min.[5]
28	.440	2240	.025	.625		0.33	50	2.5 min.	180 sec.	1.8mm/min.[5]

NOTE 1: A new lamp was installed between Run 16 and Run 17, which required less input power for the same output light intensity

NOTE 2: A controlled regrowth rate study was done with slices 23 to 28.

NOTE 3: Regrowth was by bringing the power down fast manually.

NOTE 4: Rough and general estimate of how long it took to regrow, which is based upon rate of heat loss.

NOTE 5: The power per unit area of remaining melt was reduced in 10 equally timed segments, so that at the faster growth speeds we have a rough estimate. At slower speeds, the regrowth would have steps.

ramps power linearly at a controlled rate. A second ramping speed can be used to control the latter degree of crystal growth or, as is usually done, to control the cooling of the slice below its freezing point so as to avoid cracking.

Slice zoning can be done in high vacuum, or a partial or full atmosphere of argon or with a different gas. The high vacuum minimizes gas conductive heat losses, but leads to silicon evaporation onto the quartz windows, both absorbing a lot of heat and leading to severe etching of the quartz. Argon gas atmosphere has been used for most experiments. Either high vacuum or fore-pump vacuum is used to repeatedly purge the chamber, with back-filling with Argon. The experiment shown in Table 2 used flowing argon gas at a pressure of 0.3 or 3.0 torr above atmospheric pressure.

The regrown slices are analyzed by cross-sectioning, striation etching, and observing in a microscope with Nomarski optics (as was described in Section I. A. above. In order to cut the crystals through the center to expose the cross section, they are cemented to a graphite block with epoxy, with a layer of epoxy also over the slice, to prevent chipping. They are then cut on a diamond I.D. saw. They are then hand-lapped and striation-etched, as described in reference 4. This provides a surface topographic difference for any change in growth rate, grain boundary, or crystallographic defect. Phase interference contrast microscopy (Nomarski) shows the topography difference as a color difference, thus making this method a very sensitive method and one which is applicable for surveying the entire area of many samples. This method has consistently shown melt flow instability striations in silicon crystals for many investigators, including 12 year's work by the P.I. on float zone silicon.

Since a microscope can only view surfaces perpendicular to the microscope's optical axis, and since the surface of the slice gets thinner, then thicker, a small tiltable stage was constructed for use on the microscope, thus allowing all portions of the regrown slice to be observed.

Table 2 compiles the growth parameters for a series of slices studied. Observations on many of these are included in the following section.

C. CHARACTERISTICS OF REGROWN SLICES

The melting and regrowth of silicon slices is a new type of study, unlike many years spent by the authors and others studying float zoning silicon rods; thus, many new phenomena are observed. This section will concentrate on the study of growth striations in the slices. Other observations will be mentioned, with the reader being referred to the Interim Report[1] for further description and microphotographs.

When the melt solidified, it initially becomes thinner than the original slice (and melt) according to the 11° tri-junction angle, which was repeatedly observed (solid-melt-gas). The melt interfaces were convex toward the melt with a high radius of curvature (1.9mm for a 0.625mm thick slice). As growth continues, the cross section becomes thicker, until the center "last-to-freeze" becomes a peak (see Figure 13). This creates a bulk melt flow, independent of bouyancy or Marangoni flows. Silicon also expands as it freezes (9%). All of these effects usually create a last-to-freeze bulge which has poor crystallography.

Surface flow instabilities were also observed. Figure 14 shows structure on the surface of an unetched slice, where flow causes raised flutes in the surface and radial flows cause instability in these raised flutes. These are similar to instabilities in the growth of thin films, such as emulsions.

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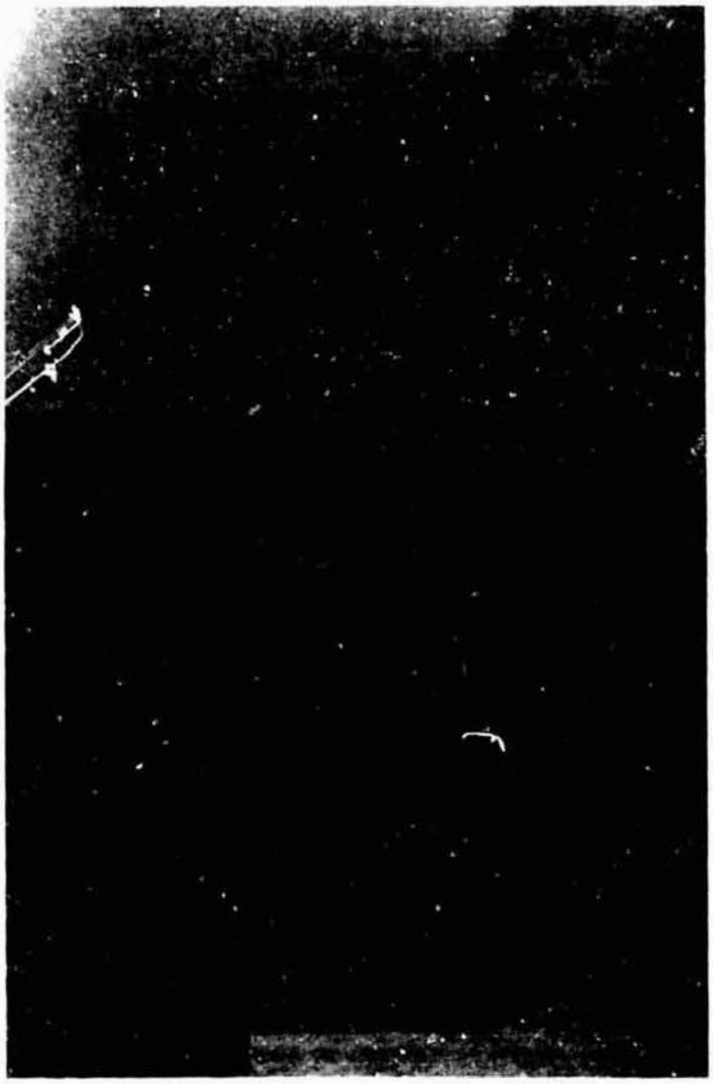

Figure 13. Cross Section of Zoned Silicon Slice.

The original slice thickness is at the right and left (0.025 inches = 0.625mm thickness). The first-to-grow crystal from the melt becomes thinner, then thicker, as it freezes toward the center. A thick cross section is the last-to-freeze, at the center.

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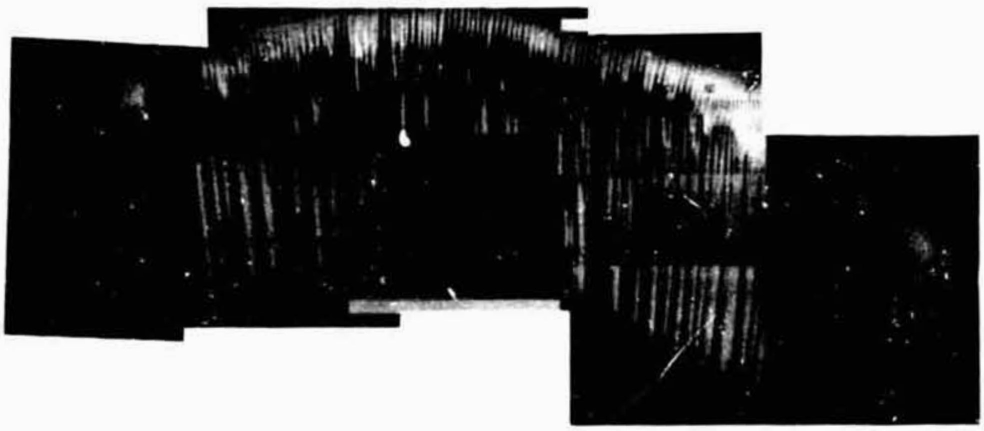


Figure 14. Surface Instabilities at the Narrow Thickness of a Slice.

Photograph of a 100x magnification photomicrograph (1 division = 11.4μm). The edge of melt is off the top of the photo. The thin lines at top are radial, then turn. The lines fade out off the bottom of the photo, as the melt thickness increases.

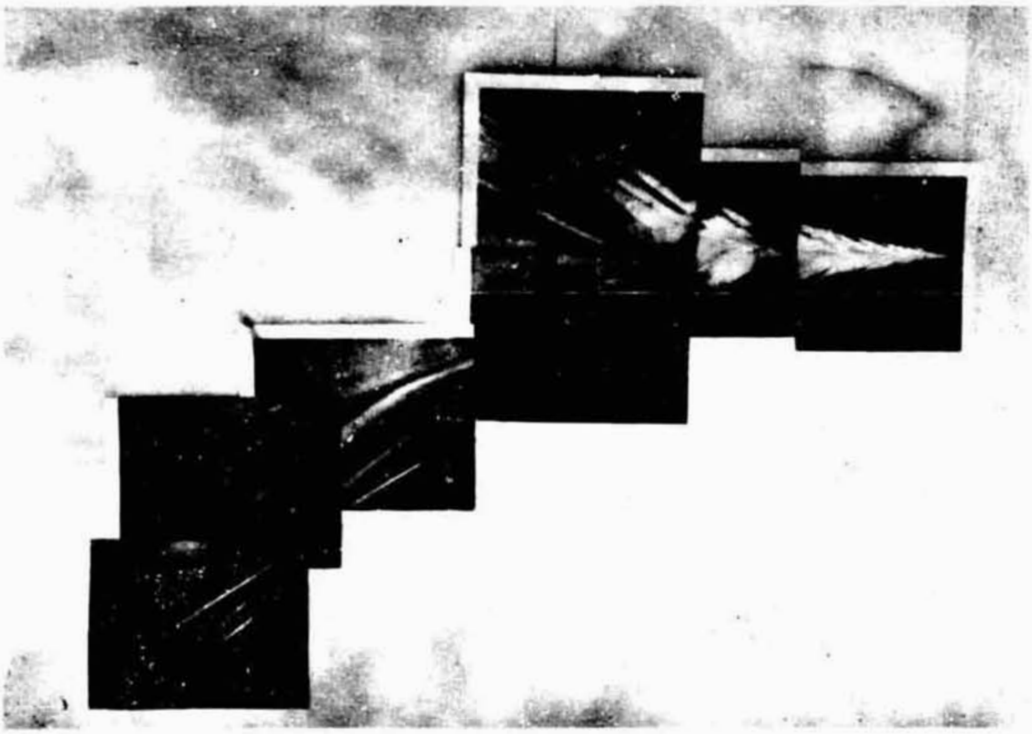


Figure 15. Instability on Surface of Last-to-Freeze Tip.

A photograph of the microphotography at 100x magnification; 1 division = 11.4μm. This curved surface is in the <100> direction on a [100] slice and is seen by tilting the slice. As the surface goes from near the slice's minimum thickness, off the left side of the photo, the wandering lines take on a regular pattern (2/3 frames), then evolve into a triangular fluted pattern going clear to the tip (right side).

Figure 16. Spiral Instability on Last-to-Freeze Cone.

This structure is on the surface of etched Slice #23. 100x magnification; 1 division = 11.4μm. One spiral starts at bottom of photograph, and another builds on top of [illegible]. The platelet structure smooths out as the last-to-freeze tip is reached, at top.

This slice (Sample #19) was regrown rapidly (estimated at 100m/min.). This sample also had an instability in the last-to-freeze tip (Figure 15). Figure 16 shows a stepped instability in the last-to-freeze tip for Sample #23, which was also grown rapidly. This instability is observed only for fast growth rates. Surface waves were modeled by Smith and Davis (5) and the Reynolds number, thermal gradient and Marangoni numbers are well above the critical numbers in their simplified model. (See Reference 1 for further analysis).

Slices grown rapidly ($\geq$33mm/min.) show the above surface topographic instabilities and striations in the direction of growth, which may have the same origin flow instability that creates the topographic instabilities.

Slices grown slowly ($\leq$5mm/min.) show no topographic instabilities and few surface striations from etching. Of the two samples showing surface striations, one was a surface relief which did not show up after etching.

Bulk striations were observed in only 5 out of 25 samples, with only three (12%) showing striations perpendicular to the growth direction, as expected for instabilities in a slowly growing crystal.

III. MARANGONI FLOW IN SILICON MELTS

A. MARANGONI FLOW IN SILICON ROD MELTS

Aperiodic (non-rotational) striations are always seen in larger diameter crystals grown by r.f. heating, as previously characterized by the authors[4]. Kölker[10] indicated that the onset of striations in silicon melts with free surfaces (suspended drops, or float zones) occurs at critical values of the Rayleigh number two orders of magnitude lower than for silicon in a container and ascribed this to the Marangoni effect, as predicted by Wilcox[21], with a low critical Marangoni number. It would thus appear that Marangoni flow could dominate the onset of melt instabilites in small melts. Above this critical Marangoni number, unstable solutions lead to periodic or pseudo-periodic (aperiodic) variations in the melt flow. These variations introduce hotter fluid to the growing interface, leading to a slowing or stopping of the growth (or even melting), followed by rapid growth which incorporates more impurities (due to the higher segregation coefficient at higher instantaneous growth rates[11]). This can be seen by spreading resistance variations in silicon[12]. These variations in the melt flow have been characterized for low temperature melts of high Prandtl number fluids by Chun[13] and Schwabe[14].

The uniformity of crystals grown in microgravity will depend largely on the magnitude and the stability/instability conditions in Marangoni flow, since bouyancy flows are eliminated. In the recent SpaceLab experiments, silicon was float-zoned by heating with a set of two elliptically focused heaters, on opposite sides of the silicon rod. Both rotational meltback striations and Marangoni instability striations were observed[9]. The rotational meltbacks were expected (by this author) due to the azimuthal temperature gradients due to the non-uniformity of the heating (about 10°C)[15]. The Marangoni instability would also be driven by both the azimuthal and axial thermal gradients. Dr. Kölker[22], using the same heating arrangement, also found many striations in a molten drop on the end of a silicon rod.

Results are not yet quantitized on the results of the latter experiment, which could provide an experimental number for the critical Marangoni number for silicon.

Theoretical studies of critical Marangoni numbers provide some insight into the extent that Marangoni flow will affect fluid flow in any float zone or free surface area process in microgravity. Xu and Davis[16] have solved for the critical Marangoni number for fluids of various Prandtl numbers for a floating zone, heated with a short ring heater in a passive gas. This compares to the thin rod zone configuration of this effort, which has a longer heater (lower temperature gradient) and is zoned in vacuum (0.1 torr Argon, thus minimizing transfer at the surface). They do make approximations that they indicate would affect predictions of flow in the end regions, which is where effects at the freezing interface will be seen from the frozen crystal, which is what we experimentally observe. Their predictions are that increasing the heat loss at the surface (which can be done by using gas instead of vacuum) should stabilize the flow. For lower surface heat loss (Biot No.= 0), an infinitely long zone and g = 0, a critical Marangoni number, M_c = 14.7 is predicted (Prandtl No. = 0.02, which applies to silicon). They indicate that bouyancy will stabilize melt flows in earth experiments (g = 1).

W. N. Gill[6] has solved for the regions of stable and unstable solutions for cylindrical zones. For float zones, Gill predicts three regions, defined by the parameter

$$\lambda = 2\left(\frac{d}{l}\right)^3 \frac{Ma}{Pr}$$

d = half depth of floating zone
l = zone length
Ma = Marangoni number
Pr = Prandtl number = 0.02 for Si

$\lambda<32$	Stable region
$32<\lambda<1750$	Only time dependent solutions
$\lambda<1750$	Stable region, with 2 or 3 solutions

Gill indicates that the floating zone (cylinder) shows the clearest evidence for unstable hydrodynamic behavior for surface tension driven flow.

Using Gill's calculation of Ma and the parameter for stability limits (λ) for the thin rod melting, the following cases are observed:

a) Diameter fully melted, not striations (Figure 1)

d = .105 inch = .26cm	Ma = 436
l = .4 inch = 1cm	
ΔT = 4.70	λ = 785

(d = radius for fully melted cylinder)

The Ma value is much higher than Xu and Davis' M_c, while the λ value is in the unstable area.

b) Thin rod pulling (initial zone processing to make the thin rod), where only striations that are almost parallel to the thin rod are observed.

d = .3c	Ma = 1483
l ≈ 1cm	
ΔT ~ 20°C (in r.f. zoner)	λ = 7820

Since this crystal is grown in an argon atmosphere, the M_c value from Xu and Davis for surface heat transfer (Biot No. = 1) is 35.4. The value of λ is in the region of stable flow with three cells (Gill).

c) 1 inch diameter crystals zoned in an r.f. zoner - which are striated.

d = 1.25cm	Ma = 3477
l = 1.5cm	
ΔT = 25°C	λ = 201,318

The Marangoni number is almost as high as in SpaceLab and λ is very high.

d) Nitsche and Eyre's SpaceLab experiment, where striation patterns are observed.

d ≈ .5cm	Ma = 5560
l = 1cm	
ΔT ≈ 60°C	λ = 69,500

(The azimuthal $\Delta T = 10°$[18] and an axial ΔT over 1cm 50° (The same assumption I use for slices using two focused elliptical heaters). The Ma is very high, while the λ value is an order cf magnitude beyond Gill's curves.

The calculations of the lower stability limit of Gill indicates there is no way to stay within that stable zone while float-zoning of silicon. His limits of the instability region do not coincide with the present experimental evidence. The small diameter rods (5.5-6mm) zoned in this effort, using a very gradual thermal gradient (4.7°C/.5cm) should be in the center of the instability region, but yet show no striations. Nitsche's experiment on SpaceLab 1 with larger rods (10mm diameter) and a high gradiant (30-60°C/.5-.7cm has a very high characteristic value (beyond Gill's curves) and does exhibit normal striations. One inch diameter crystals grown in an r.f. zoner have a higher characteristic number yet, and exhibit the oscillatory striations.

B. MARANGONI FLOW IN SILICON SLICE MELTS

The experimental observations are that striations perpendicular to the growth direction (corresponding to a toroidal fluid flow pattern in a circular thin melt cross-section) are observed in only 12% of the slices analyzed. By contrast, in one inch diameter float zoned rods, they are always observed. Gill[6] solved for regions of instability in a planar floating zone slot (except his is heated from the sides) and showed no instability region.

Smith and Davis[7] do predict bulk wave instabilities at approximately 90° to the growth direction. They have analyzed for the bulk wave instabilities in a two dimensional slot, which would correspond to the half thickness of a molten slice, from the center to the molten edge. Their model is in two dimensions and for $d \ll 1$ (thickness<<length). This would approximate a

thin slice of large diameter--and therefore at the outer extent of melt, as compared to the last-to-freeze position in our samples. They show that for low Prandtl number liquid (Si, Pr = .023), hydrothermal waves are predicted that have their axis almost perpendicular to the growth direction. Their example is for a 1mm thick silicon geometry, with a hydrothermal roll geometry at 86° to the x (growth) direction. (Since we cut our samples along a diameter, we would not observe this angle being different from 90°). The wave length of the roll for a 1mm thick slice would be 1.5cm, longer than our melt, which means that end effects (the solid silicon slice) would dampen out such an unstable wave roll. The time period between oscillations (2 seconds) is about as long as the fastest freezing times for samples of this report. While the thinner melts (.03 to .06cm) will change the frequency, it is unlikely that such oscillations could be seen at the present experimental conditions. The capillary number for our slices would be about 10^{-2}, indicating we should not see surface deformation. Surface heat transfer also stabilizes flow, which might also be taking place when we use an Argon gas pressure. The best chance to see the oscillations predicted by Smith and Davis would be to have a large diameter melt, of thicker cross-section, regrown very slowly and in vacuum.

The following are calculations for the Marangoni number and Gill's characteristic λ for zoned slices. Three regions are calculated:

a) At outer melt rim, where neither striations perpendicular to growth or surface structure parallel to growth are seen on the surface, although the latter has been seen in the interior.

$d = .0325cm$	$Ma = 462$
$l = 1cm$	
ΔT 30°C	$\lambda = 1.83$

The Marangoni number is quite high, but λ is in a stable region.

b. At the thinnest cross section of the melt, where both occasional striations perpendicular to the growth direction and sur' ~e structure parallel to the growth direction are seen.

$d = .016cm$ $\quad$ $Ma = 2225$

$l = .8cm$

$\Delta T \sim 30° C$ $\quad$ $\lambda = 1.83$

The Marangoni number is quite high, but λ is in a stable region.

c. Near the last-to-freeze peak. Some internal striations, not near the surface, are seen. Exterior structural lines, then surface relief in triangular or platelet forms are seen (see Figures 15 and 16).

$d = .145cm$ $\quad$ $Ma = 111$

$l = .12cm$

$\Delta T \sim 10°C$ $\quad$ $\lambda = 17,316$

While the Ma has a medium value, the value for λ is again an order of magnitude higher than Gill shows and of the same order of magnitude as the Nitsche SpaceLab growth system (for 10mm diamter rods).

C. DISCUSSION AND FUTURE EXPERIMENTS

The initial conclusions are that the calculated instability region limits (critical Marangoni numbers from sample models) are too low for silicon rod melts. This is to be expected, since finite zone lengths and heat extraction by conduction are expected to stabilize the flows, thus making the characteristic critical numbers higher. The small diameter rods (5.5-6mm diameter with a gradient of 4.7°C/0.5cm) should be in the center of Gill's unstable region, yet we see no striations. Nitsche's experiment on SpaceLab 1, with larger rods (10mm diameter) and higher gradients (>30°/0.5-0.7cm), has a very high λ number (beyond Gill's curves) and should be unstable, as observed. The instability limit thus lies above $M_c = 436$ (and probably >1480) but below the 3500 observed for one inch diameter r.f. zoned crystals and the approximately 5500 for Nitsche's experiment.

If we take Gill's characteristic stability number (λ) as having to be $\geq$7820, then the following ΔT over the length L could be realized in microgravity, where a zone size greater than the present 6mm diameter is possible:

Diameter 6mm	zone length 1.8cm	ΔT 99°C
1cm	1cm	6.7°C
	3cm	59.5°C
2cm	6cm	30°C
5cm	15cm	12°C
7.5cm	22.5cm	8°C
10cm	30cm	6°C

It is clear that one would have to go to long molten zones (possibly up to the Rayleigh limit of πd) and have a flat thermal profile within the zone to stay within the suggested stability limit.

Further rod zoning experiments at g=1 are needed to zone under a wide variety of growth speeds and conditions and continue to look for striations. Better definition of thermal profiles and zone characteristics should be used to support the present melt modeling efforts.

If the preliminary predictions that are presented here are close to defining M_c experimentally, then hot-wall heated zones at g=1 will not reach the instability limit. This will require longer and larger diameter zones only realizable in microgravity. Since growth of improved crystals is an important practical goal in space, the stability limit will need to be obtained experimentally.

The initial experiments in space should be with the present diameter of crystals, to confirm our ground-based results and to prove the experimental equipment. Slightly larger diameters (1cm) could be zoned in space by modification of the present heater design and could test the stability limit at 1cm. Power of up to 400 watts on the heater (600 watts total) could be accommodated by time-lining. Diameters of 2 to 2.5cm should be possible in the same zoning apparatus, by remaking the furnace assembly and time-lining the experiment for sufficient power (in the Shuttle). The total power necessary is probably slightly less than the 1400 watts available to the MSL. Further scale-up of diameter would require a new zoner unit, which might still be possible on the Shuttle if sufficient power is available.

As predicted by Gill, the silicon slice melts do not usually show melt striations. The models of Gill and Davis do not closely fit our experimental geometery. This study parallels the work by John Verhoeven on tin, where he has not yet observed striations. Further correlation to Gill and Verhoeven's tin slice work should be done. More experimental runs under varying conditions in the Slice Zoner should more clearly indicate whether or not the thermal flow striations are indeed absent. If they are, then this method cannot be used to screen methods of adding surface layers to inhibit Marangoni flow, as was originally planned. The simplicity of working with this configuration would, however, lead to this being a screening method for showing surface layer (and gas atmospheres) that could be used and still allow growth of single silicon crystals, i.e., such that the surface layers do not lead to polycrystal growth by their nature.

IV. PROTOTYPE FLOAT ZONE APPARATUS

The research float zone apparatus which was developed during the first contract period[3] proved the concept of zoning with a low power resistance heated furnace. The profile was tailored by designing and testing a series of heater designs. This led to the zoning experiments reported mid-year of this contract[1] and some of the results shown in Section I above. The original unit was modified repeatedly to attain the best zoning conditions, which also led to defining the improved features needed for reliable zoning, especially on the Space Shuttle.

The Prototype Float Zone Apparatus, described in the following sections, has been designed to be incorporated into a 36-inch high EAC (Experiment Apparatus Container) and to withstand the environmental shock and vibration necessary for Shuttle flights. Good design principles for commercial float zoner units have been used and commercial parts and assemblies are used when available. The motor controller unit built in the first contract year[3] is used and this has not been customized to an EAC and space environment configuration. That design and construction will be straightforward. Since the power (voltage and current) of the heater has been changing as the heater design is optimized, it also has not been designed and packaged for an EAC, but this, likewise, should be easily accomplished.

The packaging concept for the Flight Float Zone Apparatus is to house the zoning apparatus (heater, movements, samples) in one EAC and the power supplies, motor controls, gas atmosphere controls in a second EAC. The microprocessor controller and tape recorder now being developed for the AADSF (Advanced Automated Directional Solidification Furnace) is being and will continue to be evaluated for this application. These would be mounted on the side mounting plate of the MLS.

The Prototype Float Zone Apparatus is shown in Figure 17. This shows the unit inside the environmental vacuum belljar,

Figure 17. Prototype Float Zone Apparatus

which simulates the EAC. The design is described below by major systems: a) heater design, b) mechanical design of the zoner's structure and movement, and c) electronic control of the motors. The specifications of what the zoner is expected to do are updated (these were originally submitted to NASA in April 1984). A preliminary set of hardware specifications is included.

A. HEATER DESIGN

The key feature of a resistance heated zoning apparatus is the thermal profile that can be attained in the material being zoned. The traditional methods of zoning (r.f. coil, electron beam, hot (single) wire and focused light) have the ability to focus a large amount of power in a small area (a thin cylindrical zone). For the zoning of silicon (which is normally done with r.f. coils, but has also been successfully done with electron beam), a large amount of power goes into the center of the molten zone, with heat losses (radiative, gas convection, and solid conduction) being balanced with power input to maintain the zone length. This is not only very wasteful of power, which is an important consideration in space experimentation, but also maximized melt flows due to bouyancy flow (at g = 1) and Marangoni flow. The present experimental hot-wall heater has been designed to:

a) minimize power losses
b) minimize melt thermal gradients
c) eliminate radial thermal gradients (prevalent in r.f. coil and focused light heaters)

while controlling the zone length as to not exceed the maximum zone length that can be held by surface tension (at g = 1).

Last year several design features were redefined and heater construction material and process problems were solved[3]. The use of an alumina core tube and cements with Pt-10% Rh heater wire has been successfully developed. While higher temperature resistance wire can be used (up to Pt-40% Rh), these are stiff and brittle and not easy to work with. A quartz liner is now always used to:

a) prevent evaporated silicon from depositing on the alumina tube and changing its heat radiation characteristics,

b) prevent any gaseous components from the heater structure from contaminating the silicon melt, and

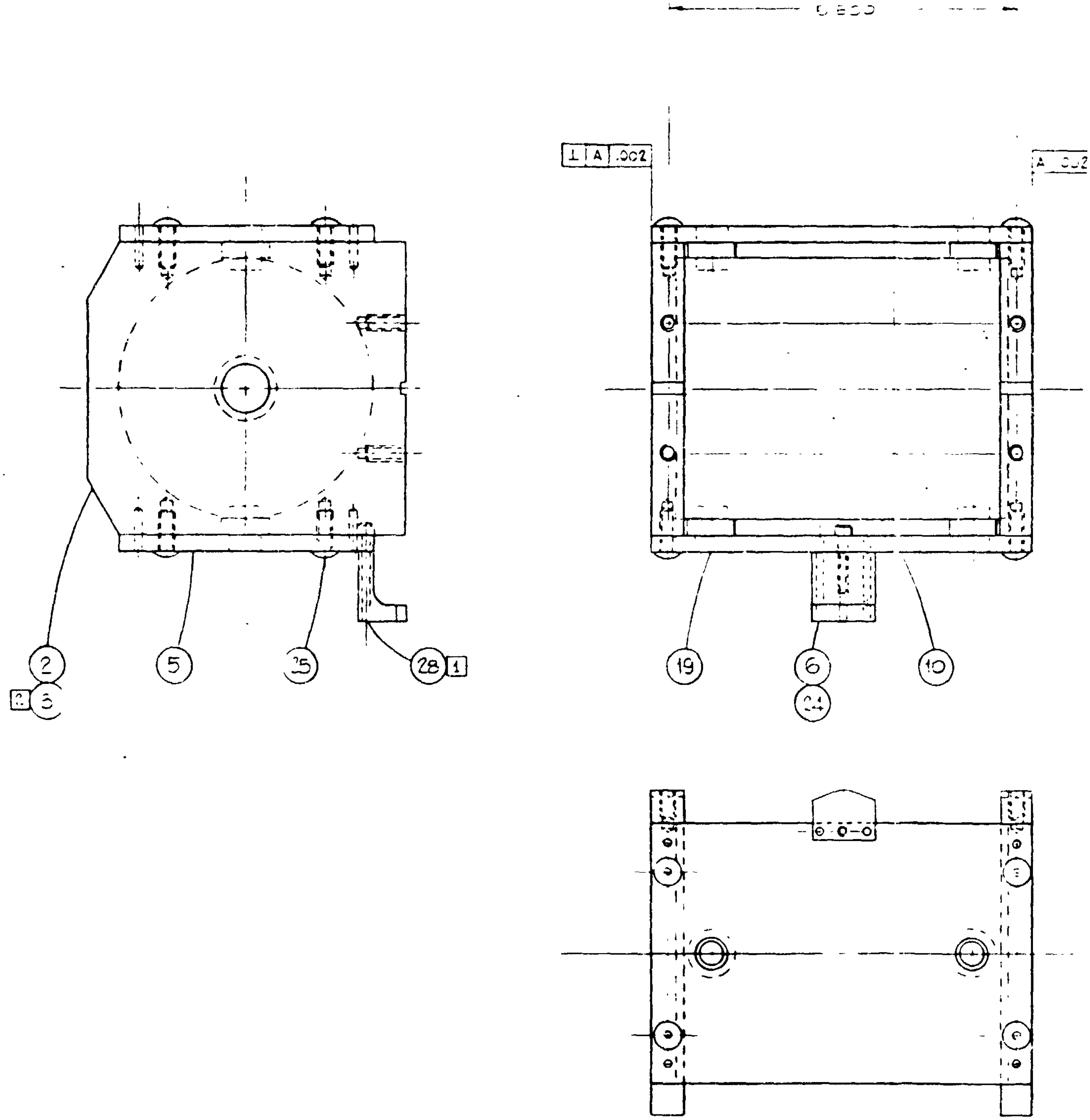
c) prevent silicon melt spills from freezing on the alumina, which shortens its useful life.

The quartz liner is changed with each sample, to prevent heating parameter changes which were observed when quartz was used for multiple runs (requiring a higher heater temperature for melting). This is caused by silicon or other films condensing on the quartz and by devitrification of the quartz at 1500°C. Because of the condensed films, it was decided not to use sapphire (which would not devitrify) and to change the liner with each silicon rod.

The outer furnace assembly drawing is shown in Figure 18 and the heater and insulation parts are shown in Figure 19 (with the bill of material following). The ends of the furnace housing have soldered aluminum cooling tubes (for water or freon) and this method is used to remove heat from the furnace. Conduction by the side walls to the ends is sufficient to keep the side walls cool (to touch).

During the contract, a series of heater designs have been tested. For ease of profiling in an open lab environment and to minimize the cost of platinum, as well as to work out construction and handling methods, Kanthal wire models are first made and tested. Optimizing operating parameters on these also minimizes the risk to the Pt heater. A series of designs are described in Table 3 and their comparative profiles are shown in Figure 20

The latest heater, designed for a sharper peak profile in order to have more flexible control on the melt zone width, is described below. Model II and earlier designs led to long melt lengths (usually $d/\ell = 1/1.5$) which leads to frequent spills.



FOLDOUT FRAME

DO NOT SCALE — WORK TO DIMENSIONS GIVEN

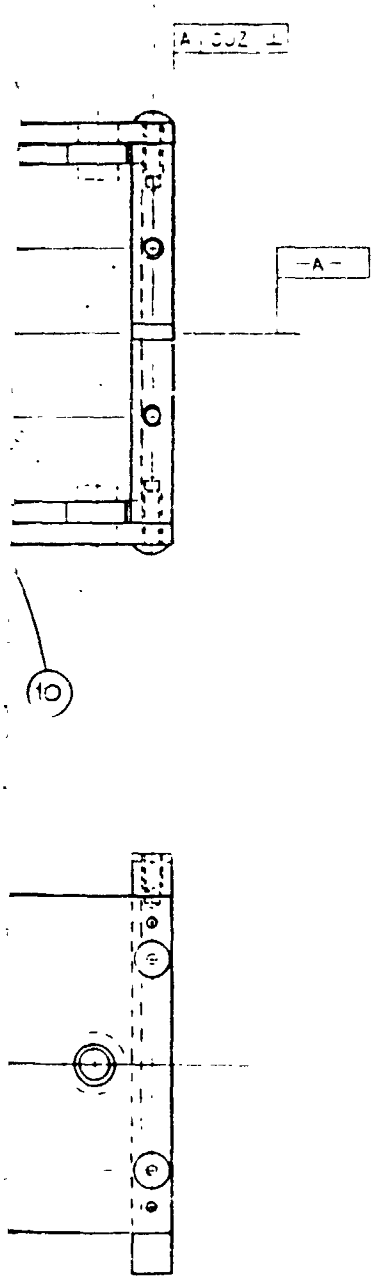


FIGURE 18. FURNACE ASSEMBLY

NOTES:

1 TRANSFER DOWEL HOLES AT ASSEMBLY AFTER ALIGNMENT

2 BRAZE COOLING TUBES AFTER PERFORMING 1

FOLDOUT FRAME

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

WESTECH SYSTEMS, INC.

FURNACE ASSEMBLY

D

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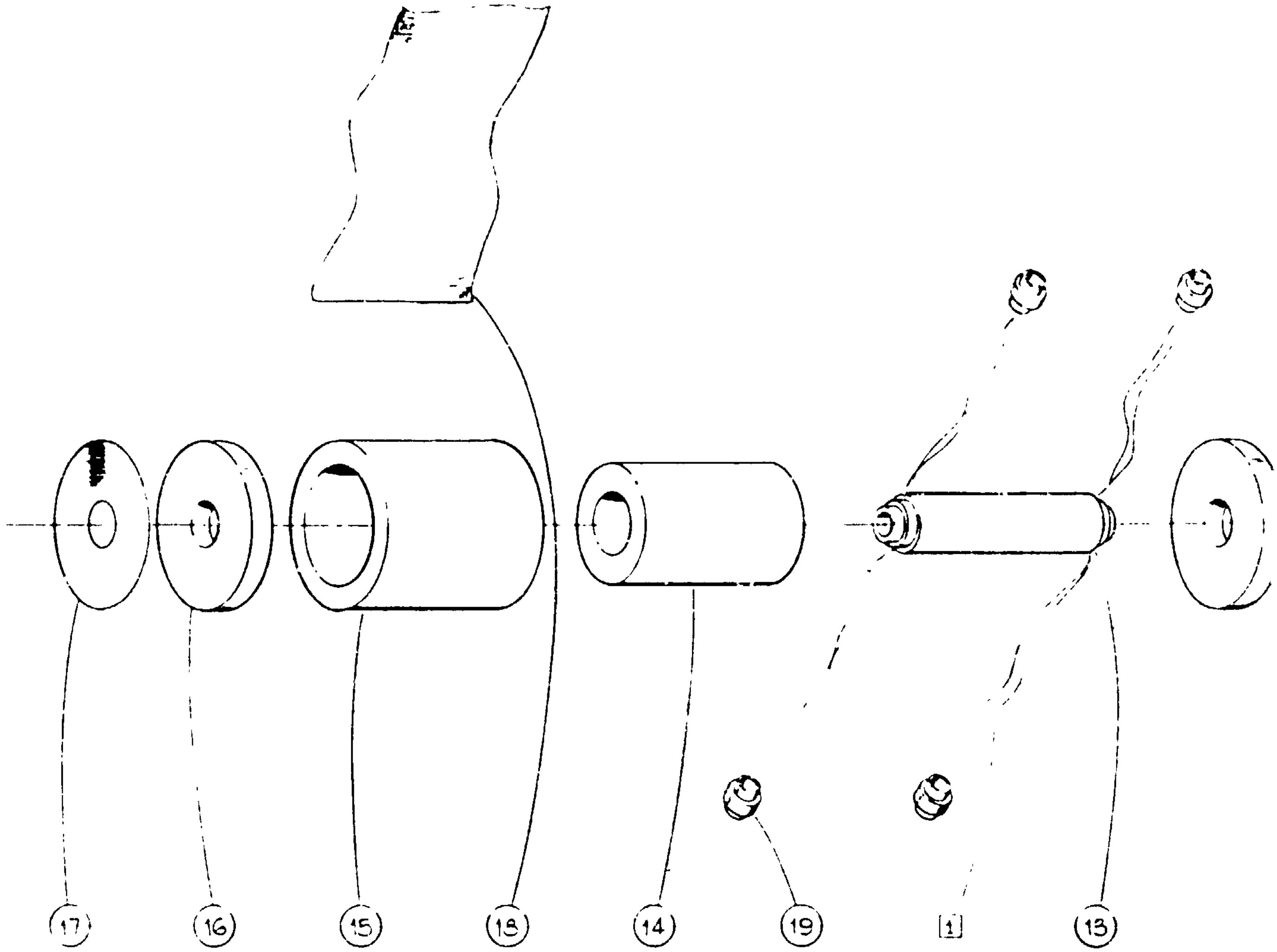

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DO NOT SCALE — WORK TO DIMENSIONS GIVEN

REVISIONS

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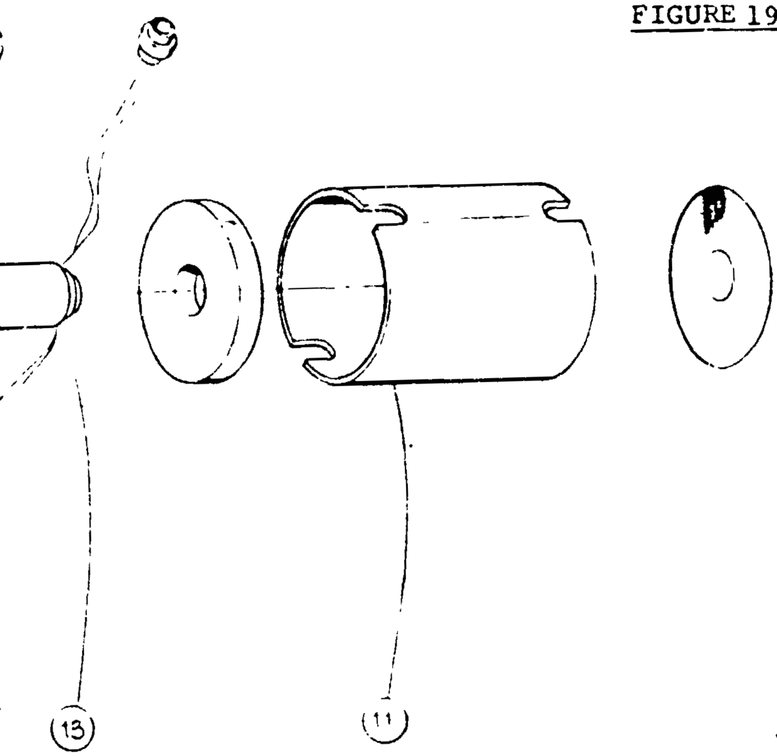
FIGURE 19. HEATER ASSEMBLY



NOTES:
1 POSITION OF LEAD WIRES AFTER ASSEMBLY

FOLDOUT FRAME

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MAT'L SPEC

PARTS LIST

WESTECH SYSTEMS, INC.

HEATER ASSEMBLY

D

1077-08119

87000

DO NOT SCALE — WORK TO DIMEN

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ITEM	REQ	PART NO.	DESCRIPTION	MATERIAL	MATL. SPEC	ITEM	REQD	
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39						19	4	IC
38						18	AS REQ'D	IC
37						17	2	IC
36						16	2	IC
35						15	1	IC
34						14	1	IC
33						13	1	IC
32						12	1	IC
31						11	1	IC
30			FITTING			10	X	IC
29						9		
28	10		SPRING PIN .125Ø x .63	10-125-0625	GROOVE PIN CORP	8	REF	IC
27						7		
26	4		SOC HD CAP SCREW	1/4-20UNC x .75		6	1	IC
25	8		BUTON HD CAP SCREW	1/4-20 UNC x .63		5	2	IC
24	1		SOC. HD CAP SCREW	#8-32NC x .63		4	2	IC
23						3	REF	IC
22						2	2	IC
21						1	X	IC

1 / UNIT

UNLESS OTHERW
1. DIM ARE IN INCHE
2. TOL ON: DECIMAL
XXX ±
3. SURFACE ROUGH
PER ANSI B46.1
4. INTERPRET DIM G
5. REMOVE BURRS A
0.005 TO 0.015
6. MACHINED FILLET
7. DIM LIMITS HELD
8. MACHINED DIA'S
CENTER LINE TO
WITHIN 0.005 DIA.

MATERIAL

NEXT ASSY	USED ON
APPLICATION	

FOLDOUT FRAME

1077-08120

WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
LC	A	ITEM 28 WAS 8 REQ'D, ADDED ITEMS 6 & 24	19 SEP 84	

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FIGURE 19a. FURNACE ASSEMBLY BILL OF MATERIAL

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20					
19	4	1077-08118	INSULATOR-WIRE	.38ϕ×.50ϕ×.70	ALUMINA
18	AS REQ'D	1077-08124	INSULATOR CLOTH	4.25 × AS REQ'D	↑
17	2	1077-08123	INSULATOR DISK-CLOTH	3.63ϕ	ZIRCONIA CLOTH ZYW 30A
16	2	1077-08126	INSULATOR DISK	3.63ϕ×.50	
15	1	1077-08121	INSULATOR 3.63ϕ	2.69ϕ×3.63ϕ×4.25	ZIRCONIA ZYC
14	1	1077-08122	INSULATOR 2.63ϕ	1.38ϕ×2.63ϕ×4.25	↓
13	1	1077-08127	CORE TUBE	.75ϕ×.50ϕ×6.00	ALUMINA
12	1	1077-08117	LINER		QUARTZ
11	1	1077-08114	HEATER SHELL	4.00ϕ×.19W×5.25	AL. 6061-T6
10	X	1077-08119	HEATER ASSEMBLY		
9					
8	REF	1077-08115	SLIDER-MODIFIED	B6000 SERIES	
7					
6	1	1077-08125	CAM-LS	L2.0×2.0×.25×1.00	↑
5	2	1077-08113	SIDE PLATE	.25×4.00×6.00	AL 6061-T6
4	2	1077-08109	FORMED TUBE -4	.25ϕ×.049W×20	HYD. LINE TUBING AL 6061-T6
3	REF	1077-08116	WELDM'T-END PLATE WATER COOLED	MF ITEM 2	
2	2	1077-08112	END PLATE	.50×5.00×4.50	AL TOOL'G PLATE
1	X	1077-08111	FURNACE ASSEMBLY		

PARTS LIST

UNLESS OTHERWISE SPECIFIED

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS XXX ± XX ± ANGLES ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	ZUNKER	19 Jul 84
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.	OBENFIELD	8/8/84
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL

APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

TITLE BILL OF MATERIAL ASSEMBLY FURNACE

SIZE B | FSCM NO. | DRAWING NUMBER 1077-08120 | REV.

SCALE | WEIGHT | SHEET | OF

2 FOLDOUT FRAME

TABLE 3 - HEATER DESIGN FEATURES

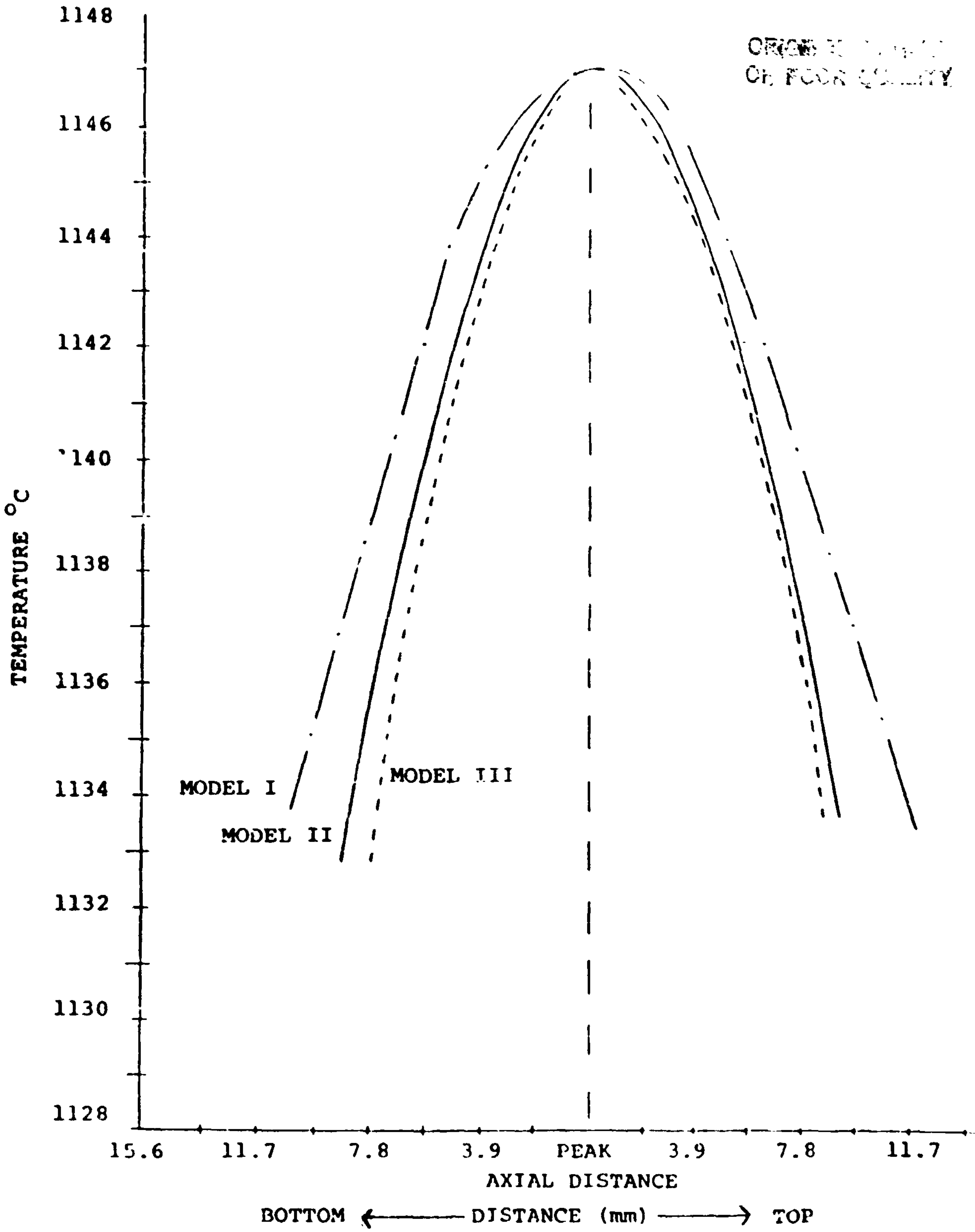
WINDING INFORMATION (4 INCH WOUND LENGTHS)

	BOTTOM 1-1/2" LENGTH	MIDDLE 3/16" LENGTH	TOP 2-5/16" LENGTH
Model III (# of turns Primary)	0	1	0
Model III (# of turns Secondary)	3	1	5
Model II (# of turns Primary)	9-1/2	1	12
Model II (# of turns Secondary)	3	1	5
Model I (# of turns Primary)	9-1/2	2	12
Model I (# of turns Secondary)	3	2	5

MATERIALS OF CONSTRUCTION

	MODEL I	MODEL II	MODEL III
Core AL_2O_3 Dimensions	.375" x .500"	.500" x .750"	.550" x .785"
Winding Material Diameter	Pt 10% Rh .032"	Pt 10% Rh .032"	Pt 10% Rh .032"
Thermocouples	5 3 at peak zone 1 at each end Pt-Pt 13% Rh .015"	5 As in Model I As in Model I	3 All at peak Zone As in Model I
Insulates	Alumina Cement Ceramabond 569 (low silica)	Alumina Cement Ceramabond 569 (low silica)	Alumina Cement Ceramabond 569 (low silica)

FIGURE 20. COMPARISON OF PROFILES OBTAINED FROM MODEL I, II, AND III. Pt 10% Rh Heaters



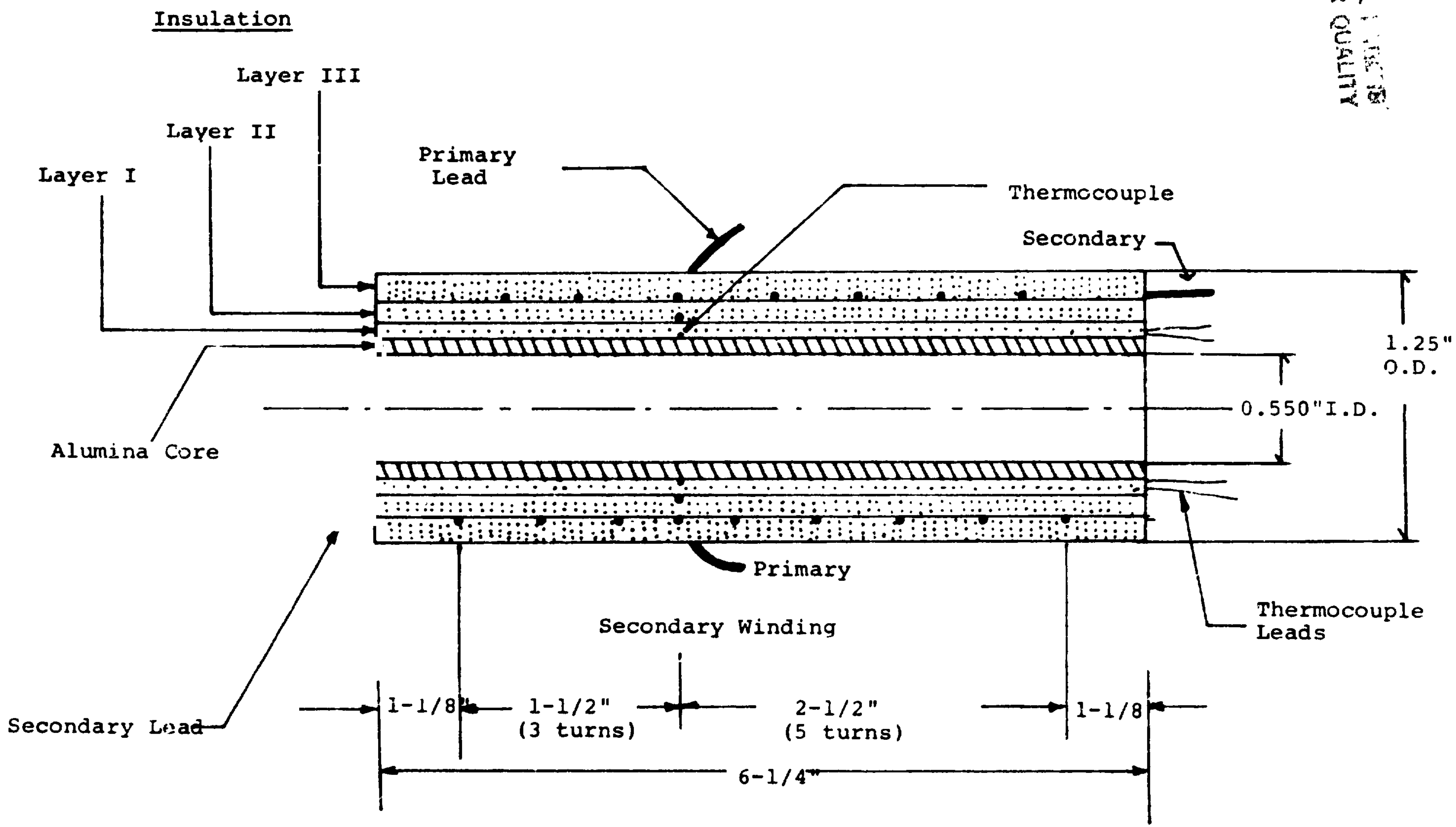
A thin melt zone and a sharper peak are thus desired. The core diameter was also increased to allow more space between the silicon melt and the quartz liner, such that a melt can sag (not spill) and still not touch the liner, as has happened previously.

Based on the information obtained from the Kanthal model heater (Model III), the Model III high temperature (Pt-10% Rh) heater was designed and constructed. For any given heater element the peak zone length would be a function of a) the winding spacings of the primary and secondary coils, b) the power distribution between the primary and secondary coil, c) the thickness of the alumina core onto which the coils are wound, d) the thickness of insulation between the coil layers, e) the insulation thickness covering the secondary coil, and f) the thermal conductivities of each material of construction. Since the relationship between these variables and the peak temperature zone had not been established, it was necessary to experimentally find out the optimum power distribution (between primary and secondary coils) for the narrowest possible peak temperature zone.

The design of the heating element for the zoner is based upon a Kanthal heater of similar design, which has been profiled and the relationship between parameters has been determined. The heater is fabricated by the techniques, developed during the two years of this contract, which provide for a reliable operation (at temperature) of 200-300 hours. Figure 21 shows the schematic cross-section of heater Model III. The primary winding is a single turn of Pt-10% Rh wire. This is similar to a "tickler coil" commonly used to provide high thermal gradients. Between the alumina core and this coil are three thermocouples, spaced 120° apart (the redundancy is in case one or two burn out or break) to measure the peak temperature and is used to control the heater power.

The secondary coil has 8 turns, spaced as shown. The thermal peak is 0.5 inch below the heater center (for earth zoning) so as to provide for heating of the feed portion of the rod and

FIGURE 21. MODEL III HEATER ELEMENT SCHEMATIC



extracting heat from the solidifying end. Table 4 indicates the specification of each material used. The insulating layers are applied in thin layers and carefully cured in order not to have the ceramic insulation flake. The heater is then placed inside the furnace housing (see in Figure 18) and is surrounded with a low heat conducting ZrO_2 ceramic foam which has been machined to fit the outside of the heater.

The thermal profile is optimized by varying the power distribution between the primary and secondary coils. While it would seem that the sharpest thermal peak (as pictured in Figure 23) would result from most of the current going through the single turn primary coil, this is not the case. Figure 22 shows isotherms at peak temperature -n°C (n = 0.5, 1, 2 and 4) at distances from the location of the peak temperature for different ratios of power on the primary coil (as compared to the secondary).

For this heater design, it is found that for 22% power on the primary coil, the narrowest possible temperature zone is achieved.

The temperature profile along the axis of the heater is shown in Figure 22 for the above power distribution. The (Peak - 0.5)°C zone in the present heater measures less than 1.5mm, compared to 3.33mm obtained on the heater shown in the Interim Report.[1] The maximum temperature attained during the profiling experiments was 1148°C rather than ~1500°C, in order to have a prolonged life of the heater element. Profiling studies have shown that profiling at lower temperatures leads to reliable sets of optimizing conditions and that the temperature profile gradient is larger at higher temperatures, due to higher end losses. By comparison to earlier operating models of the Pt heaters, the expected operational life at the temperatures of 1500°C is 200 hours.

TABLE 4. PLATINUM HEATER MATERIAL SPECIFICATIONS

Alumina Core:	0.550" I.D. 0.785" O.D.
Thermocouple Leads:	at ends - Primary, none
Heater Wire:	Pt 10% Rh (Supplier Englehard)
Insulation Layers:	Low silica, Alumina cement (Supplier AREMCO Ceramics, Ceramabond #569)

Windings:	Bottom 1-1/2"	- Primary, 0 turns	- Secondary, 3 turns
	Middle 3/16"	- Primary, 1 turn	- Secondary, 1 turn
	Top 2-5/16"	- Primary, 0 turns	- Secondary, 5 turns

FIGURE 22. COIL POWER DISTRIBUTION FOR SHARPEST THERMAL PEAK

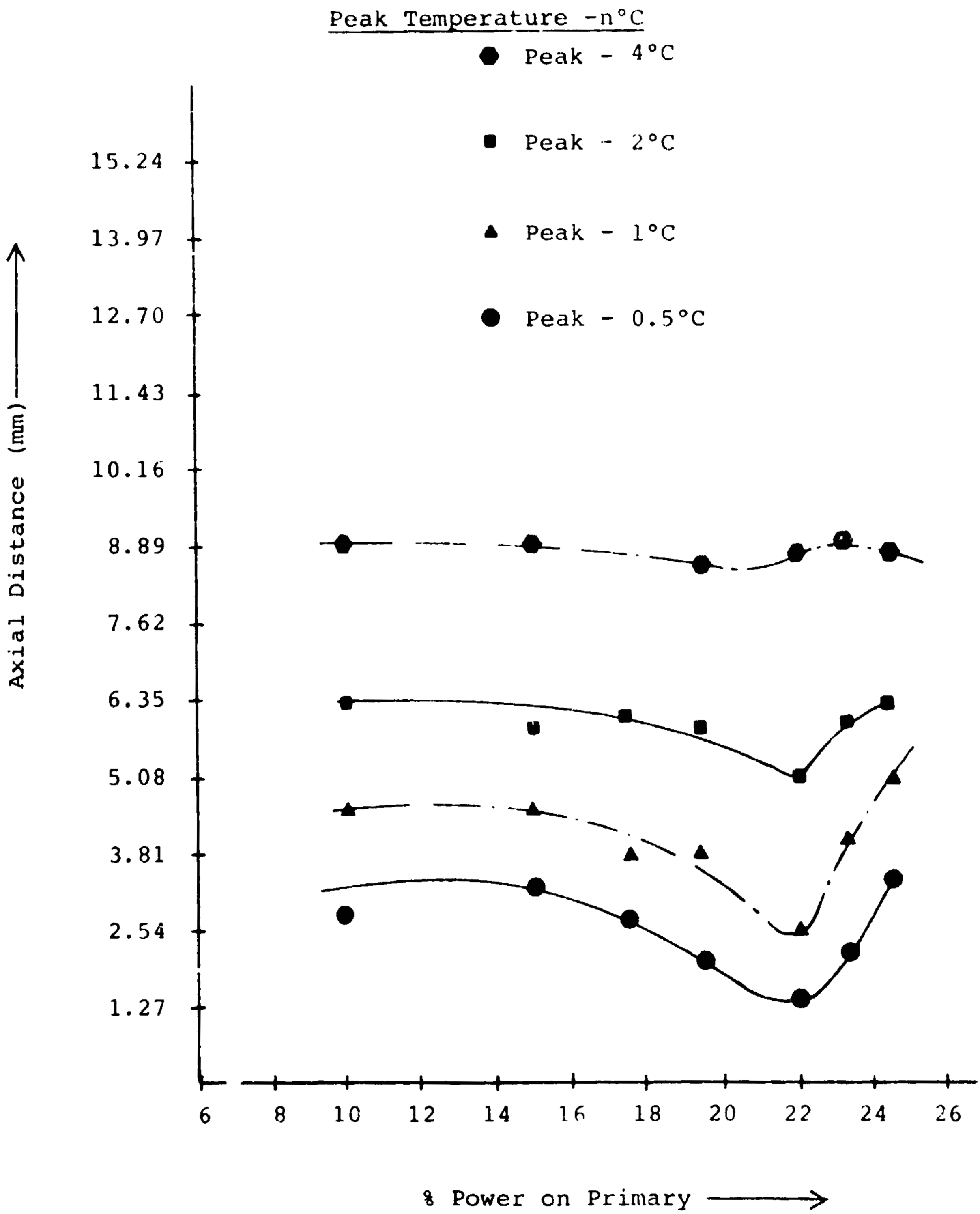
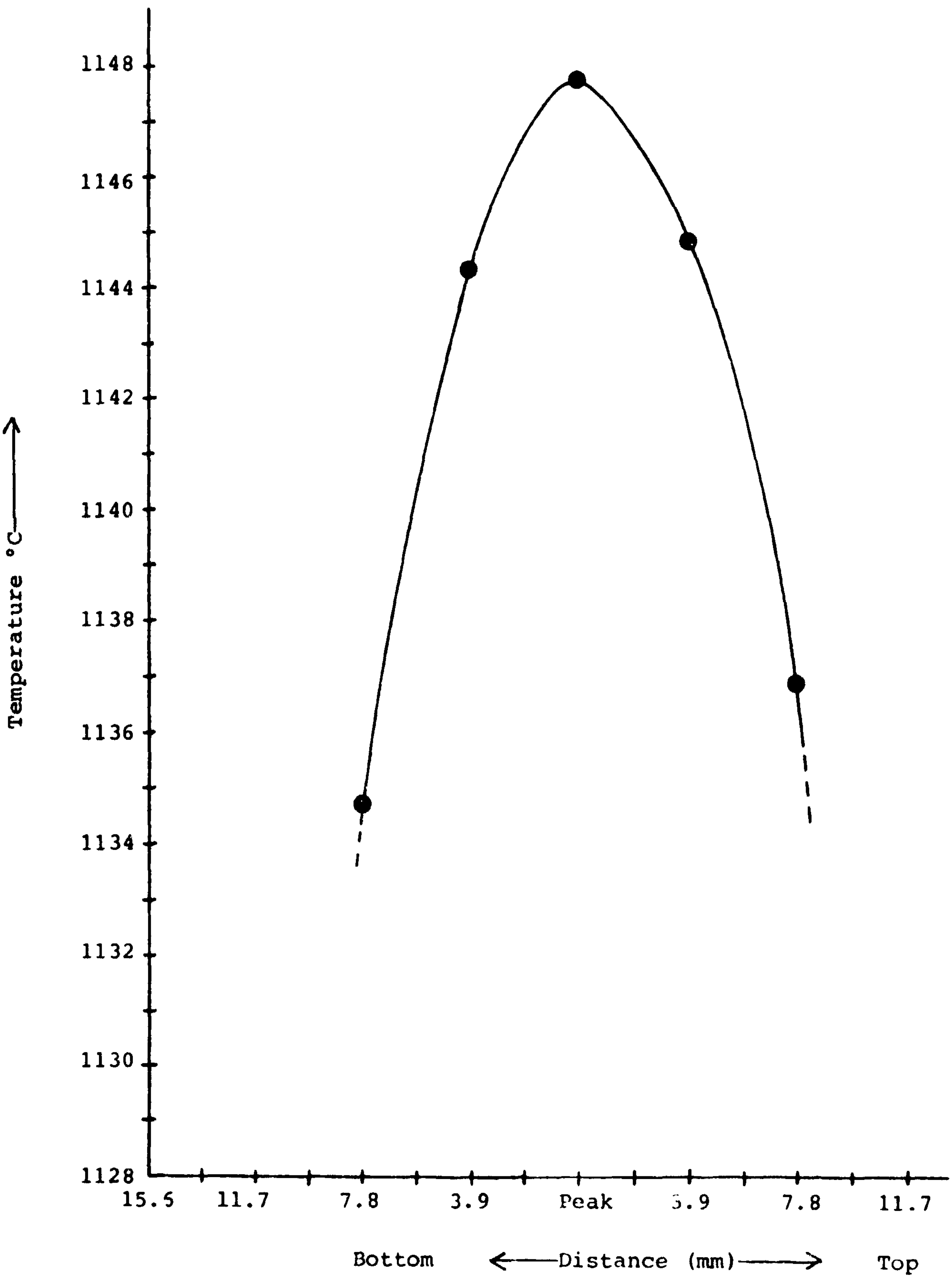


FIGURE 23. TEMPERATURE PROFILE FOR HEATER MODEL III



B. MECHANCIAL DESIGN OF THE THIN ROD ZONER

1. INTRODUCTION

The previous contract period saw construction of a Thin Rod Zoner which serves as a breadboard for the science experiments, and provides for acquiring data on furnace performance. It is a test bed for ideas for the flight version. Using this background experience, a new Thin Rod Zoner of simpler design and improved performance was constructed. This part of the report will describe the new Zoner and the reasoning behind the various design decisions. Discussion of the Zoner as a whole will involve the various sub-assemblies; these will be discussed in detail in following paragraphs.

Difficulties in the zoning of silicon crystals indicated that the first Thin Rod Zoner needed better alignment and vibrational stability. These were suspected for the spill of several melts as the melt volume approached the limit sustainable by surface tension, where stability will be most critical. In the design of the Prototype Zoner, the areas of a) precise and non-stressed silicon sample holding, b) maintaining good sample and furnace alignment, and c) non-vibrating movement and a high natural frequency of the equipment were stressed.

The following major areas were addressed in the design of the new zoner:

1. Alignment
2. Rigidity
3. Weight
4. Size
5. Movement precision
6. Repeatability
7. Melt thru detection
8. Material preparation
9. Multiple samples
10. Pressure and atmosphere
11. Heat removel
12. Power budget

a. Alignment

Construction and operation of the prototype zoner pointed out several areas of concern. Alignment of

a. Alignment (continued)

the top and bottom chucks for both concentricity and axis parallelism is crucial in that the sample could move after melt through and contact the interior wall of the furnace. This is catastrophic because the sample bonds to the wall, which not only ended the experiment but requires that the entire mechanism be disassembled to remove the silicon. The mis-alignment was caused by two things: the drive mechanisms were not concentric, and the sample chuck's design made use of flexible gripping fingers that did not provide an adequate method of axial alignment. Specifics of the new chuck and furnace will be discussed in succeeding paragraphs.

b. Structural Rigidity

Structural rigidity is necessary to ensure that crystal growth is not detrimentally affected by mechanical operation of the machine. Sources of mechanical noise and a natural vibration frequency of the zoner structure in the frequency range of the silicon rod being zoned can lead to vibrations in the melt. When these are severe (during resonance) bad crystal structure or melt spill can result. It is also necessary to ensure that the multi-axis multi-G inertia loads imposed by takeoff, re-entry, and landing do not affect alignment; this is especially important to the operation of the automatic sample holder. Both alignment and rigidity are assured by the use of a commercially manufactured dovetail slide mechanism that is designed to possess these qualities (refer to drawing no. 1077-08075). The cross-section of the slide (part no. 2) can be seen in the top view; this is an inherently rigid section. Note also the added support that is provided by the stiffener (part no. 10); this component also serves as a mount for other parts. The slide is made with three movable slide parts. The top rotation assembly, the furance, and the bottom rotation assembly are securely fastened to top, mid and bottom sliding parts, respectively. Vertical movements of the bottom rotation and furnace are via precision lead screws that are controlled by gearhead servomotors. The upper rotation assembly is positioned by a handwheel; this will be done by motor in the flight version. Alignment inaccuracy is limited to clearance in the slide assembly and manufacturing clearances in the slide, both of which are less than one thousandths inch.

c. Precision and Repeatability

Precision and repeatability are important for two reasons--uniform growth, and precise positioning for sample changing. These needs are met by use of closed loop velocity servomotor controls and high precision mechanical components. The present motor control is an analog system, but the flight unit will use a crystal time base digital system developed by Westech Systems for commercial use that is capable of 0.01% accuracy.

d. Material Preparation

Material preparation is also crucial; perfectly aligned chucks and furnace are to no avail if the sample rods are crooked or of non-uniform diameter on the ends. Currently used are polysilicon rods grown on a commercial slim rod puller (Westech Model 1004) that are straight as grown. End preparation will consist of concentrically grinding one inch of each end to a uniform diameter, then silver plating the ends and silver brazing a sleeve with an inboard flange on each end (drawing no. 1077-08180). Thus the rods are assured of secure yet stress free retention.

e. Pressure Control

The prototype zoner provided local pressure control for the furnace by enclosing it in a small vacuum chamber. This poses some serious design problems when automated sample changing is included. Zoning pressure and atmosphere is 0.1 torr Argon, therefo... neither high vacuum nor high pressure techniques are necessary. It is feasible to simply evacuate the interior of the cannister, especially since the control systems and gas systems will be stored in a separate EAC. This method allows the arrangement shown in the drawing (no. 1077-08075); the new furnace assembly is simply bolted onto the slide, thus assuring a rigid and accurate alignment that reduces the complexity of the structure, while nicely meeting the pressure and atmospheric needs. Pressure regulation will be controlled by ventir.g the cannister into space and flowing the required quantity of Argon into the system.

The EAC that contains the Electronics, Gas and Controls Package will need to be pressurized at one atmosphere; it may prove desirable to use an inert gas such as Nitrogen or Argon. This will be determined in ground based experiments.

f. Melt Through

It is necessary to be able to determine the exact moment when the crystal melts through. Movement of the furnace cannot begin until this occurs. It was originally thought possible to inject a current into the top chuck then measure the change of voltage that occurs at melt-through. This method requires that the chucks be electrically isolated, which complicates the design. A simpler method uses a magnetic clutch of low torque capability to couple the rotation force from the bottom

f. Melt Through (continued)

chuck drive to the chuck, but allows the clutch to slip before melt-through occurs. The motion of the chuck is monitored by either optical or magnetic means; when it stops, melt-through has occurred.

The clutch has sufficient torque to allow rotation during zoning if this is required. Details of the design are discussed in following paragraphs, in the section covering the bottom chuck drive.

The flight version will utilize an Eddy Current Clutch rather than the permanent magnet; this will assure greater reliability and control of torque.

g. Power Budget

The total power consumption now contemplated is within the power budget for each experiment on the MSL, without time-lining for additional power. This simplifies the scheduling of experimental runs.

Worst case power consumption for the various units is shown below. The power conversion loss occurs on reduction of the 24vDC to 5vDC and 12vDC necessary for the computer, heater, and motor control circuitry. This is the worst case; nominal usage could be reduced as much as one-half.

Heater	200 watts
Heater control	20
Computer	40
Motors (4)	40
Analog controls	40
Gas controls	50
Power conversion loss	75
Total	465 watts
Allowed	470 watts

h. Cooling Requirements

Equally important as the power requirements are the cooling needs. Cooling required should not exceed the electrical power input. Re-design of the heater included a great amount of simplification because the cooling was found to be much less than originally planned. This will be discussed in the paragraphs specific to the heater.

i. Multiple Samples

The time needed to experimentally grow a silicon crystal, even with a series of different sequential conditions, is 2 to 3 hours. Flight opportunities are scheduled far in advance and turnaround time for experiments is 1/2 to 1 year. Growing more than one crystal rod would allow many more parameter studies and speed up the research.

The concept of running several experiments was addressed briefly in previous contract reports and proposals. Re-design of the zoner included a concept design of a sample changing mechanism that is quite simple yet should offer a high degree of reliability. We believe that flight time is of high value and that it would be inappropriate to trust in one run on one sample to obtain the results desired. A detailed discussion of the mechanism is presented in the following paragraphs.

2. THE THIN ROD ZONER

This section will describe, item by item, the Thin Rod Zoner's major assemblies (refer to drawing no. 1077-08075 and Bill of Material drawing no. 1077-08150). The item numbers will correspond to the drawing numbers. Self-explanatory items such as screws and nuts, etc., will be omitted. An asterisk denotes an assembly that will be fully discussed separately.

2. The Thin Rod Zoner (continued)

(2) Unislide. A precision dovetail slide mechanism with three separate slides, one each for the furnace, the upper, and the lower rotation drives.

(4) Base Plate Assembly. Bottom structural member to which all other components are mounted.

(5) Furnace Assembly*

(6) Upper Rotation Drive*

(7) Lower Rotation Drive, with Clutch*

(8) Lower Chuck Assembly*

(9) Frame Member. Serves as a mount for the sample changer and other components.

(10) Stiffener. Serves to mount the shelves for the sample holder and provides additional vertical rigidity.

(11) Shelf, Lower. Serves as a mount for the sample changer.

(12) Shelf, Upper. Serves as a mount for the sample changer.

(14) Limit Switch Mounts. Adjustable mount for the limit switches.

(16) Sample Holder. Automatically replaces a zoned rod with a new sample. See additional paragraphs.

(40) Limit Switches. Mark the travel limits for the rotation assemblies.

3. DESCRIPTION OF MAJOR ASSEMBLIES

a. Sample Holder

Drawing no. 1077-08170 and Bill of Material no. 1077-08160

The sample holder holds six rods. Operation of the unit is as follows (refer to drawing no. 1077-08075). At the end of a crystal growth run, the furnace is at the bottom of its travel. The bottom chuck is opened and the top rotation assembly moved to a loading position near the top of its travel. At this point a clear space exists between the furnace top and the bottom of the top rotation assembly, with the zoned rod suspended from the top chuck; the sample holder can now be moved into position. A drive and positioning mechanism rotates the unit into position to receive the zoned rod. The rod is released from the top chuck and is gripped by the sample holder; spring tension of sufficient force to overcome the G-forces involved is applied to the rod ends to retain the samples in place. The top rotation assembly is then moved to the top of its travel and the sample holder rotates the new rod into position. The top rotation assembly is then moved down into the load position where the top chuck grasps the rod. The sample holder is rotated into the run position. The top rotation assembly is moved down to allow the rod to enter the bottom chuck. The furnace is moved to its top position to begin the next run.

The sample holder as depicted in these drawings does not show positioning components; this unit requires a rotational drive to position the sample in line with the chucks and a sensing system to determine that it is properly aligned. (This part of the design has not been completed.)

(2) Shaft. The center shaft supports the arms and serves as a pivot.

(3) Spacer. Positions the arms in relation to the shelves.

(4) Spacer. Positions the arms in relation to the shelves.

(5) Arm. The center arm supports the middle of the sample rods.

(10) Arm, lower. The sample rods are retained and positioned by the arm.

(11) Spring, leaf. This spring provides the force to retain the sample rod in the arm.

(15) Arm, upper. The sample rods are retained and positioned by the arm.

(16) Spring, leaf, (rh). This spring provides the force to retain the sample rod in the arm.

(17) Spring, leaf, (lh). This spring provides the force to retain the sample rod in the arm.

(20) Silicon sample rod.

b. Upper Rotation Drive

Drawing no. 1077-08093 and Bill of Material No. 1077-08100

The upper rod rotation rotates the feed silicon rod to even out slight thermal fluctuations or to alter growth conditions such as growth interface shape. The upper rotation drive consists of a drive motor and housing, appropriate gearing and drive chain, and a chuck assembly with mounting axle and bearings. Various mounting plates complete the assembly.

The motors that are commonly available are not designed to be used in a vacuum; this is provided for by housing them in an aluminum shell which is sealed to the motor spacer with an o-ring. The motor shaft is sealed where it exits the spacer. Wiring egress is via EMI suppressing feedthroughs. This housing can be sealed in either air or inert gas, as desired.

Refer to chuck assembly drawing no. 1077-08043 and Bill of Material 1077-08040.

Alignment of the silicon rod is critical and is assured by the design of the chuck, which utilizes a precision v-block to hold the rod. A spring leaded lever applies pressure to the rod to retain it in the "v", thus the rod is firmly retained while still allowing ready insertion and removal.

(2) Plate, side. Serves as a structural member to locate items 5 and 6.

(3) Plate, back. Structural. as ove.

(4) Spacer bar. Structural, as above.

(5) Plate, motor bearing. Mounting plate for the rotation gearhead motor.

(6) Plate, bearing. Mounting plate for the chuck bearing.

(8) Chuck assembly.

(9) Shaft. Axle shaft for the chuck.

(19) Key. Top and bottom keys assure proper alignment of the assembly on the slide (Item No. 2, drawing no. 1077-08075).

(22) **Flanged** nyliner. Shaft support bearing.

(23) **Flanged** nyliner. Shaft support bearing.

(30) **Sprocket.** Chuck shaft sprocket.

(31) **Sprocket.** Motor shaft sprocket.

(32) **Ladder** chain. Chuck drive chain

c. Lower Rotation Drive

Drawing no. 1077-08077 and Bill of Material no. 1077-08110
The lower rotation rotates the seed, varying growth conditions and assuring a straight crystal.

(2) **Plate, side***

(3) **Plate, back***

(4) **Spacer bar***

(5) **Plate, motor bearing***

(6) **Plate, bearing***

(8) **Chuck assembly***

(9) **Assembly,** magnet shaft. Axle shaft for the magnet and the drive sprocket.

(11) **Shaft, motor***

(12) **Housing, motor***

(13) **Spacer, motor***

A clutch unit has been designed to allow the seed rotation to slip before melt-through and to rotate at a different speed from the feed rod when melted through. Attaching a sensor for this slip ceasing can be a monitoring method for determining melt-through.

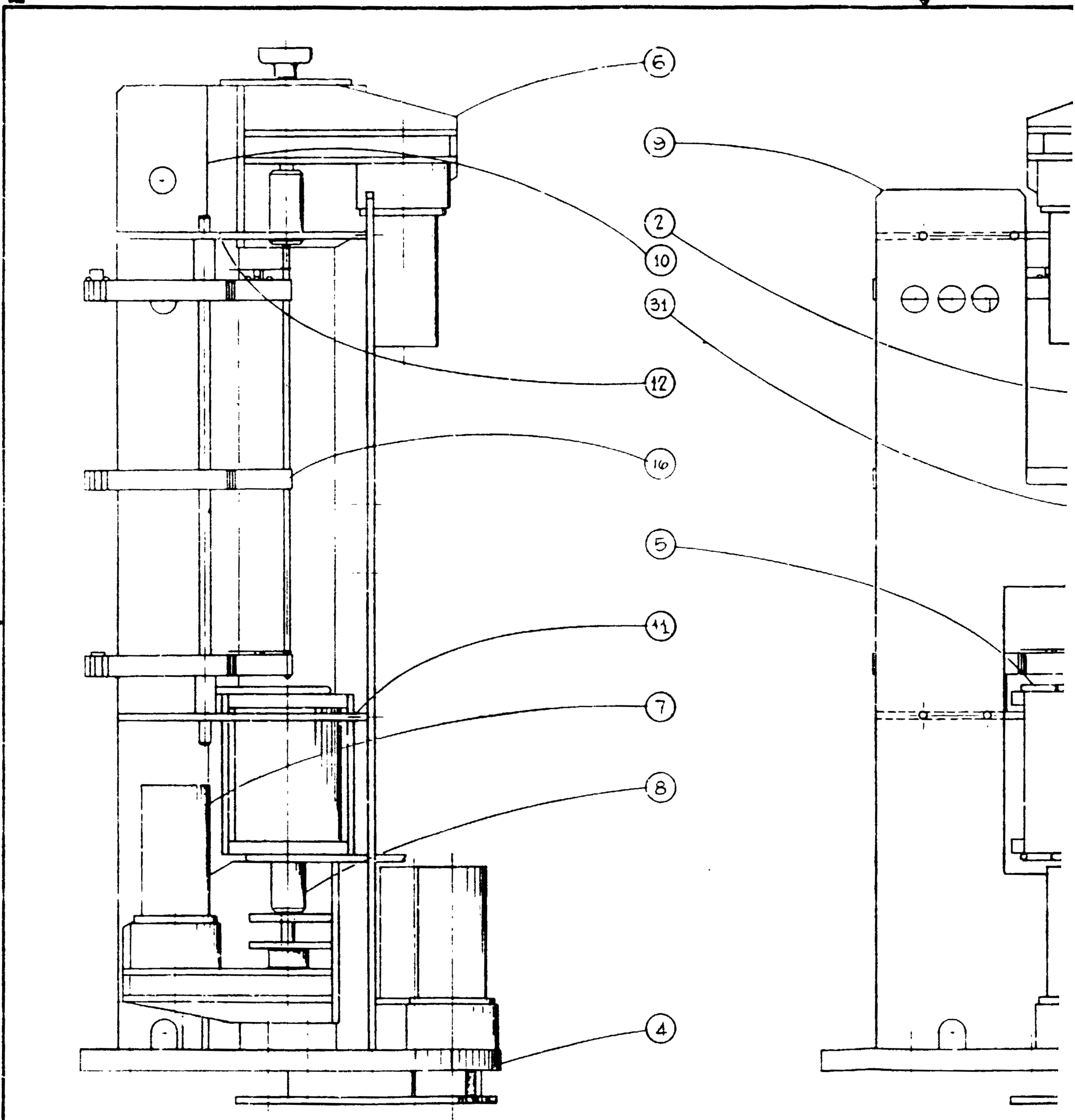
(16) Cup shaft. This shaft is driven by the clutch cup; it is pinned to the chuck.

(18) Cup, clutch. (Refer to drawing no. 1077- 08098) The toothed cup part of the assembly is rotated by the six pole magnet, item no. 41.

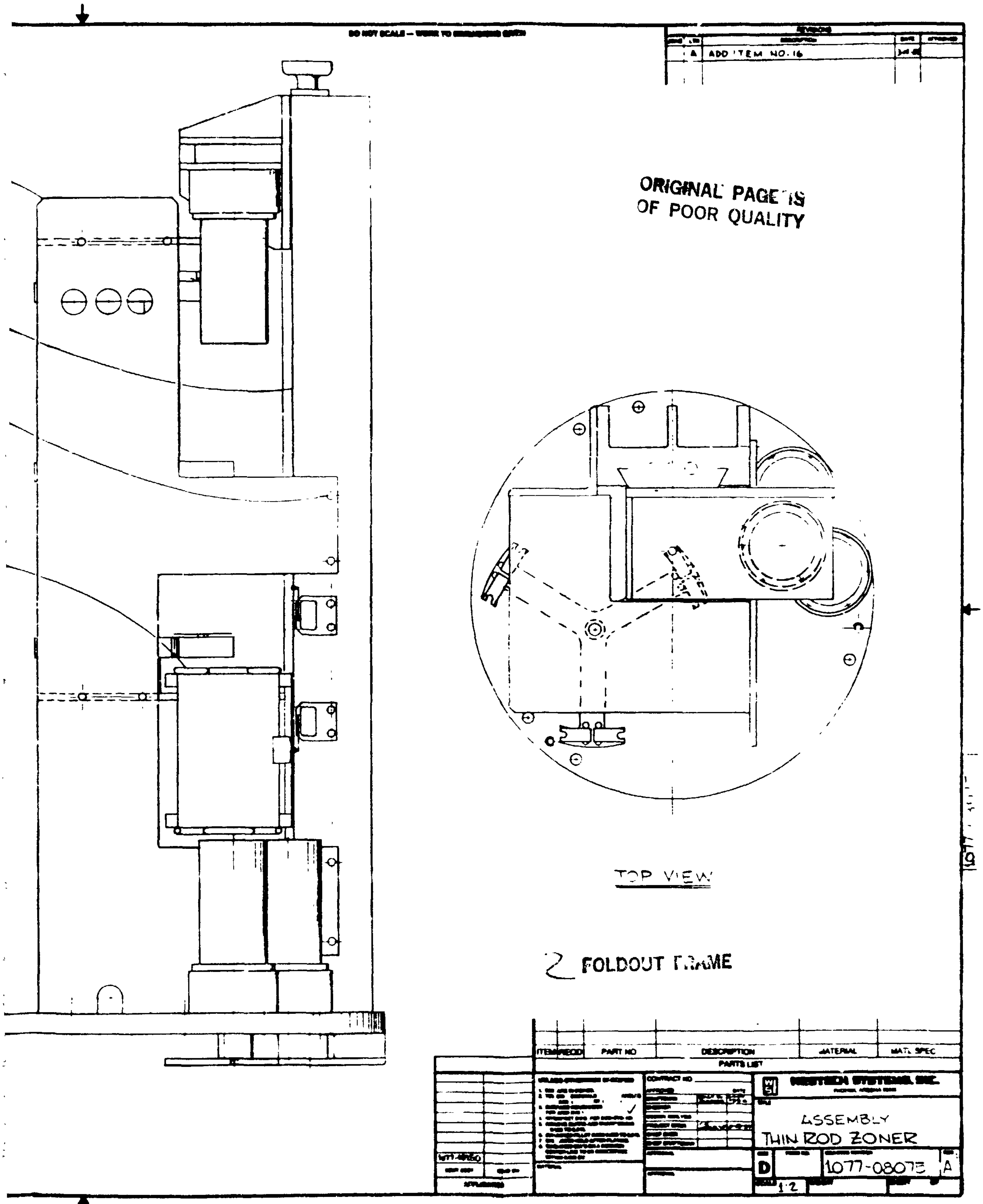
(20) Plate, chuck bearings. This arrangement is slightly different from the upper unit to accommodate the added magnetic drive components.

(21) Key*

(22) Flanged nyliner*



FOLDOUT FRAME


DO NOT SCALE — WORK TO DIMENSIONS GIVEN
A ADD ITEM NO. 16
TOP VIEW
2 FOLDOUT FRAME
ITEM REQD PART NO DESCRIPTION MATERIAL MATL SPEC
PARTS LIST
ASSEMBLY
THIN ROD ZONER
D
1077-08073
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DO NOT SCALE — WORK TO DIMEN

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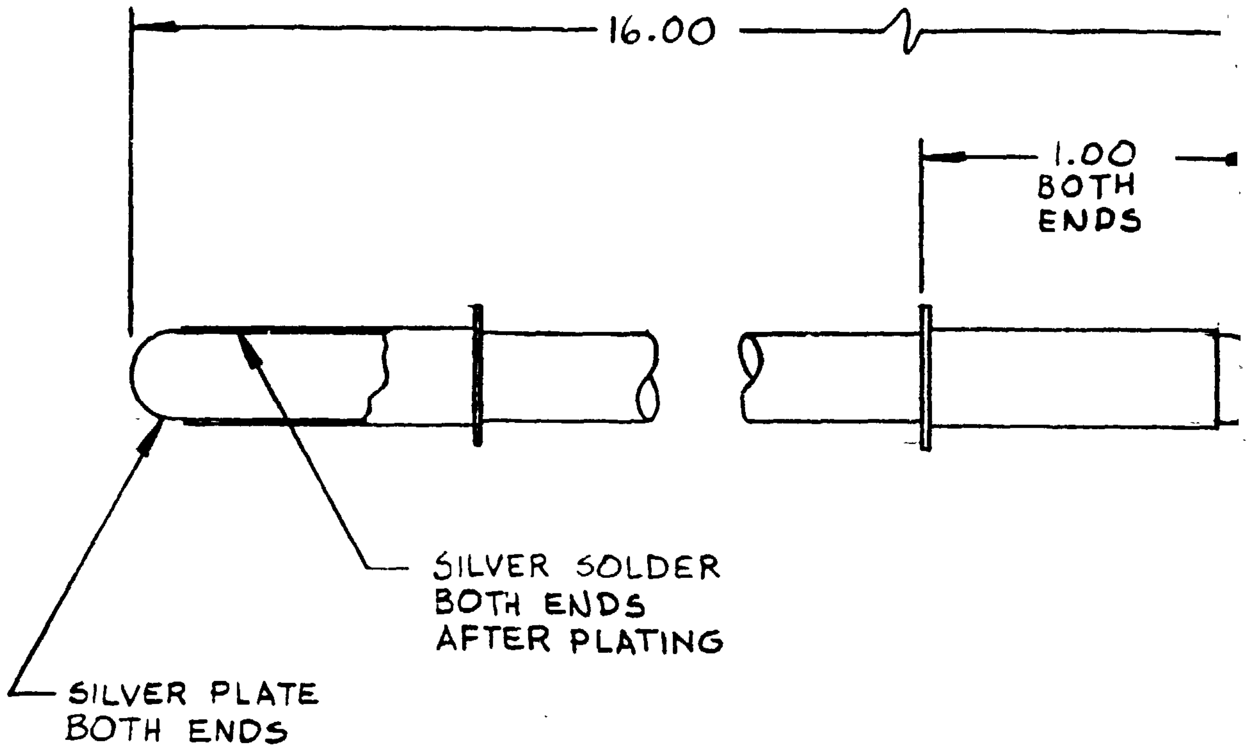

ITEM	REQD	P.

UNLESS OTHERWISE SP

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS
XXX ± XX ±
3. SURFACE ROUGHNESS
PER ANSI B46.1
4. INTERPRET DWG PER DOD
5. REMOVE BURRS AND SHAR
0.005 TO 0.015.
6. MACHINED FILLET RADII
7. DIM LIMITS HELD AFTER P
8. MACHINED DIA'S ON A COM
CENTER LINE TO BE CONC
WITHIN 0.005 DIA.

MATERIAL

NEXT ASSY	USED ON
	1077-08170

APPLICATION

FOLDOUT FRAME

— WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

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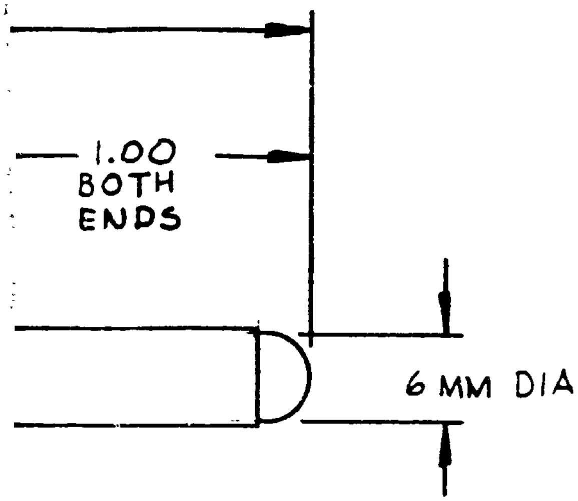


FOLDOUT FRAME

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

UNLESS OTHERWISE SPECIFIED
1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS XXX ± XX ± ANGLES ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	JH	3-14-85
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.		
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL

APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

TITLE
ASSEMBLY - SILICON SAMPLE

SIZE	FSCM NO.	DRAWING NUMBER	REV.
B		1077-08180	

SCALE	WEIGHT	SHEET	OF
2/1		1	1

88584

DO NOT SCALE — WORK TO DIMENSI

ITEM	REQ	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
45					
44					
43					
42					
41					
40	4		LIMIT SWITCH	E 21	CHERRY ELECTRIC PRODUCTS CORP
39					
38					
37					
36					
35	2		NYLINER-FLANGED, BEARING	8L3½-F	THOMSON INDUSTRIES, INC.
34					
33					
32	15		FLUSH, SELF-CLINCHING FASTENER	F-832-2 #8-32 NC	PENN ENGINEERING & MFG CORP
31	8		BUT. HD CAP SCREW	#8-32NC×.63	
30	8		SOC. HD CAP SCREW	#4-40NC×.56	
29	2		SOC. HD CAP SCREW	#8-32NC×1.00	
28					
27					
26					
25					
24					
23					
22					
21					

ITEM	REQD	P
20		
19		
18		
17		
16	1	1077
15		
14	4	107
13		
12	1	107
11	1	107
10	1	107
9	1	107
8	2	107
7	1	107
6	1	107
5	1	107
4	1	107
3	1	107
2	1	107
1		107

1 / UNIT

NEXT ASSY	USED ON

APPLICATION

UNLESS OTHERWISE

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS .XXX ± .XX
3. SURFACE ROUGHNESS PER ANSI B46.1
4. INTERPRET DWG PER
5. REMOVE BURRS AND S 0.005 TO 0.015.
6. MACHINED FILLET RADI
7. DIM LIMITS HELD AFTER
   MACHINED DIA'S ON A CENTER LINE TO BE CO WITHIN 0.005 DIA.

MATERIAL

FOLDOUT FRAME

WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	IT. 31 WAS 8 REQ'D	1 NOV 84	BG

2 FOLDOUT FRAME

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20					
19					
18					
17					
16	1	1077-08170	ASSY-SAMPLE HOLDER		
15					
14	4	1077 08155	MOUNT-LS	.25×1.50×1.63	AL 6061-T6
13					
12	1	1077-08161	SHELF-UPPER	.25×8.50×9.50	↑
11	1	1077-08162	SHELF-LOWER	.25×8.50×9.50	
10	1	1077-08159	STIFFENER	L3.5×3.5×.25×36	
9	1	1077-08158	MEMBER-FRAME	.25×12.00×32.00	AL 6061-T6
8	2	1077-08036	LOWER CHUCK ASSEMBLY		
7	1	1077-08110	LOWER ROTATION DRIVE, CLUTCHED		
6	1	1077-08100	UPPER ROTATION DRIVE		
5	1	1077-08120	FURNACE ASSEMBLY		
4	1	1077-08140	BASE PLATE ASSEMBLY		
3	1	1077-08156	LS MOUNT DRILLING		
2	1	1077-08130	UNISLIDE-MODIFIED		
1	X	1077-08075	THIN ROD ZONER ASSEMBLY		

PARTS LIST

UNLESS OTHERWISE SPECIFIED

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS XXX ± XX ± ANGLES ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	WILLY H. BUNKER	18 SEPT 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.	[illegible]	7/18/84
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL

APPROVAL BG

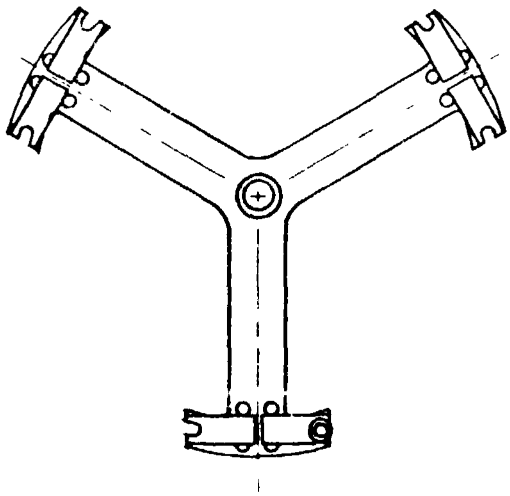
WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

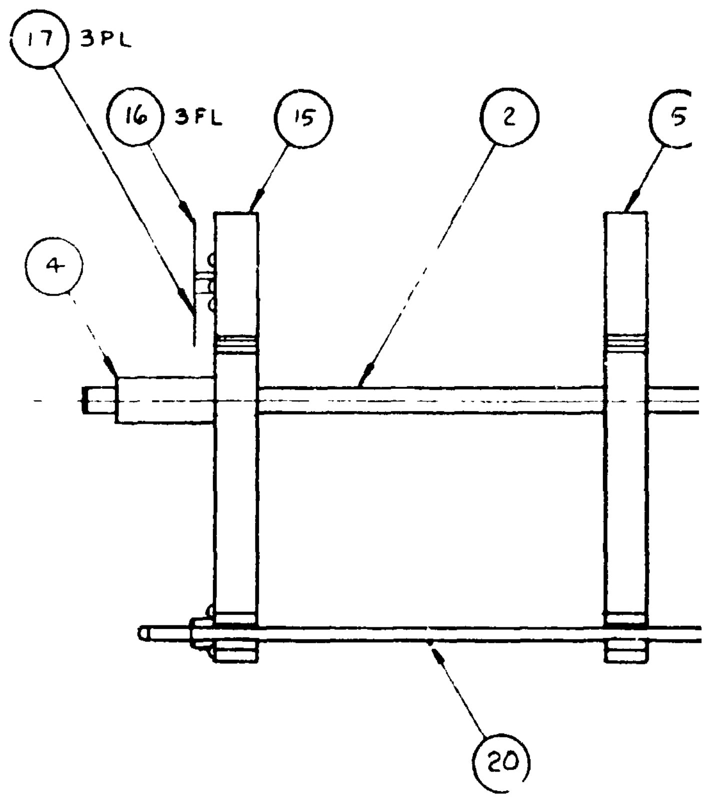
TITLE BILL OF MATERIAL ASSEMBLY THIN ROD ZONER

SIZE B | FSCM NO. | DRAWING NUMBER 1077-08160 | REV.

SCALE | WEIGHT | SHEET OF

DO NOT SCALE — WORK TO DIMENSIONS GIVEN



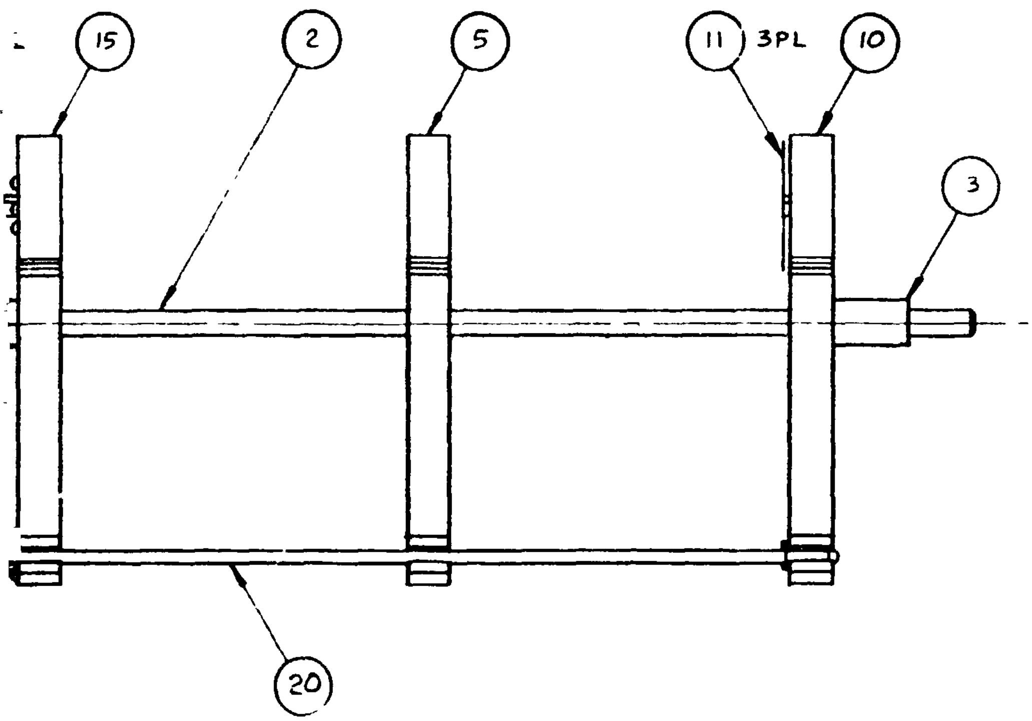


1077-08160	1077-08075
NEXT ASSY	USED ON
APPLICATION	

FOLDOUT FRAME

DO NOT SCALE — WORK TO DIMENSIONS GIVEN

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



FOLDOUT FRAME

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

1077-08160	1077-08075
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED

CONTRACT NO

APPROVED — DATE

CRAFTSMAN — JH

PHOENIX, ARIZONA

ASSEMBLY – SAMPLE HOLDER

C — 1077-08170

1/2

SHEET 1 OF 1

DO NOT SCALE — WORK TO DIMENSIONS

IT.	REQ	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
40					
39					
38					
37					
36					
35					
34					
33					
32					
31					
30	6		SOC HD CAP SCREW	#4-40NC x .56	
29	3		SOC SET SCREW	[illegible]-32NC x .25	
28					
27					
26					
25					
24					
23					
22					
21					

ITEM	REQD	PART
20		
19		
18		
17	1	1077-C
16	1	1077-C
15	1	1077-C
14		
13		
12		
11	1	1077-C
10	1	1077-C
9		
8		
7		
6		
5	3	1077-C
4	1	1077-C
3	1	1C77-C
2	1	1077-C
1	X	1077-C

1 / UNIT

NEXT ASSY	USED ON

APPLICATION

UNLESS OTHERWISE SPEC

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS XXX ± XX ±
3. SURFACE ROUGHNESS PER ANSI [illegible]
4. INTERPRET DWG PER DOD-ST
5. REMOVE BURRS AND SHARP 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030
7. DIM LIMITS HELD AFTER PLA
8. MACHINED DIA'S ON A COMM CENTER LINE TO BE CONCENTR WITHIN 0.005 DIA.

MATERIAL

1077-08160

— WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20					
19					
18					
17	1	1077-08171	SPRING-LEAF (LF)	↑	↑
16	1	1077-08171	SPRING-LEAF (RH)	.040 x .92 x 2.06	GRADE A SPRING PHOSPHOR BRONZE-ALLOY #510
15	1	1077-08168	ARM - UPPER MF	1077-08166	
14					
13					
12					
11	1	1077-08163	[illegible]RING - LEAF	.032 x .50 x 3.38	GRADE A SPRING PHOSPHOR BRONZE-ALLOY #510
10	1	1077-08167	ARM - LOWER MF	1077-08166	
9					
8					
7					
6					
5	3	1077-08166	ARM	.75 x 2.50 x 5.13	AL 6061-T6
4	1	1077-08165	SPACER - ROUND	.750Ø x .500Ø x 1.81	NYLON
3	1	1077-08164	SPACER - ROUND	.750Ø x .500Ø x 1.38	↓
2	1	1077-08163	SHAFT	.500Ø x 19.69	POLISHED DRILL ROD
1	X	1077-08076	ASSY, HOLDER - SAMPLE		

PARTS LIST

UNLESS OTHERWISE SPECIFIED

1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS ANGLES
   .XXX ± .XX ± ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	WILLY H. ZUNKER	8 NOV 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR		
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL

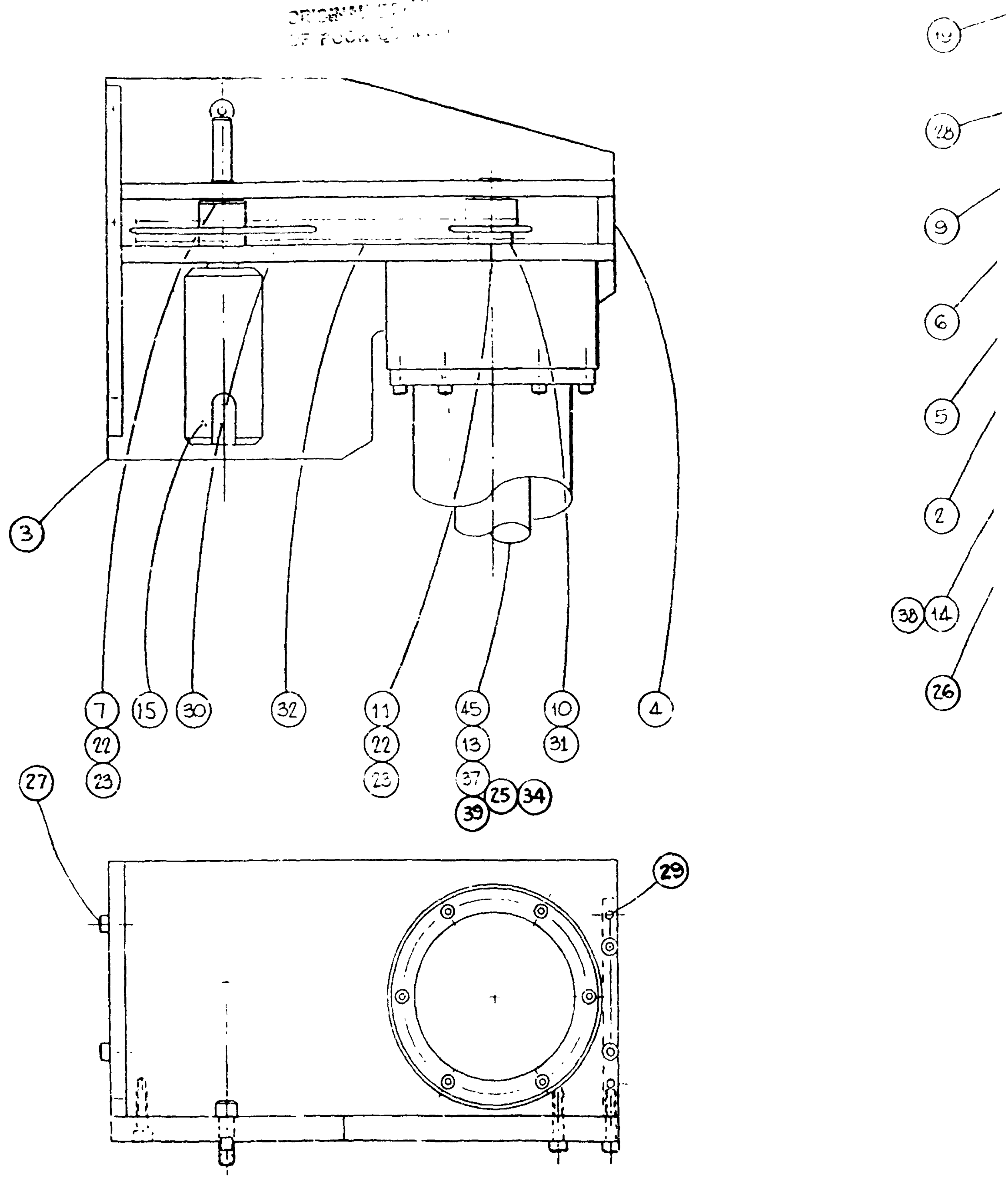
APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

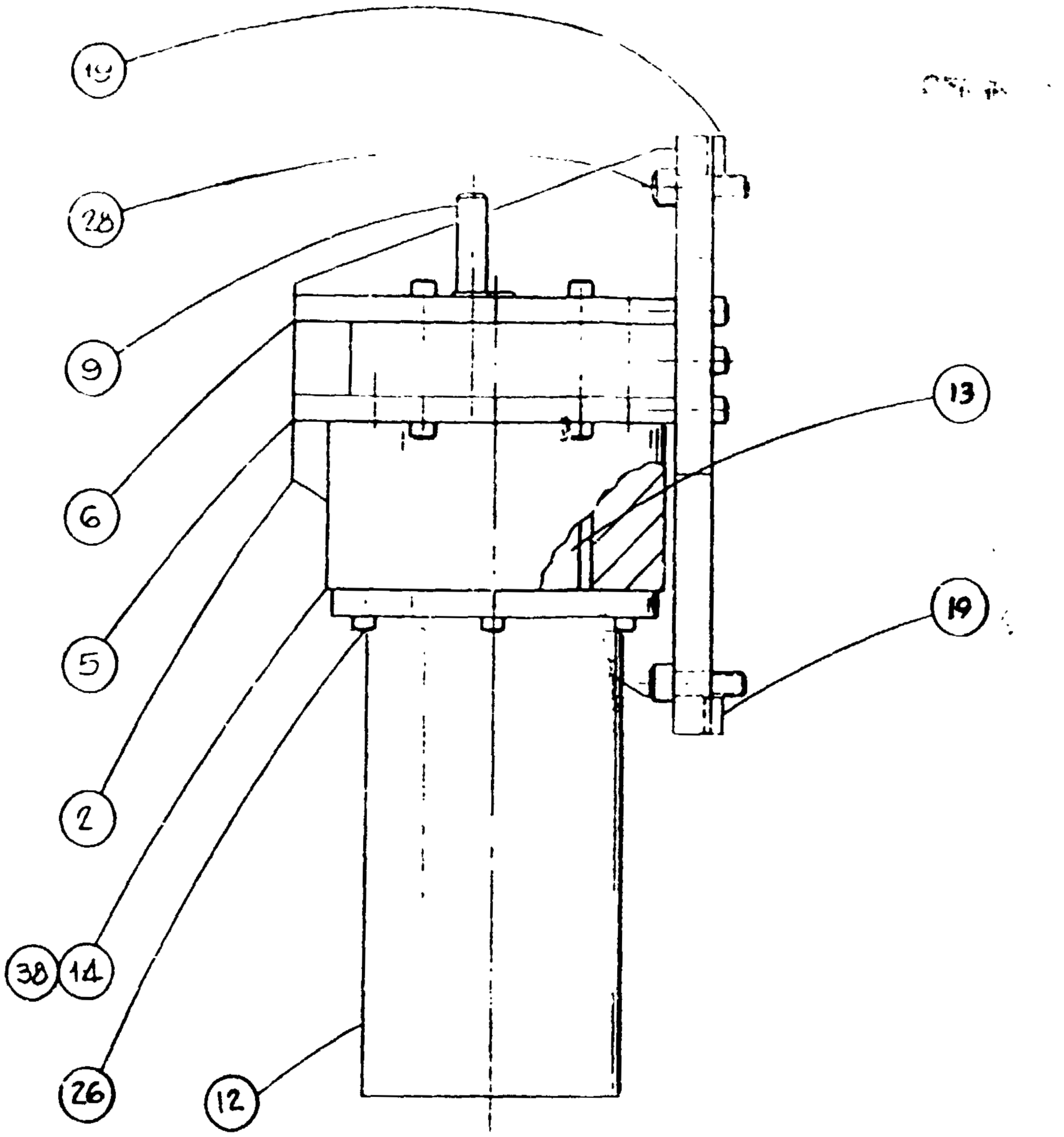
TITLE
BILL OF MATERIAL
ASSEMBLY
HOLDER-SAMPLE

SIZE	FSCM NO.	DRAWING NUMBER	REV.
B		1077-08160	

SCALE — WEIGHT SHEET OF



FOLDOUT FRAME



2 FOLDOUT FRAME

BEFORE FINAL ASSEMBLY, SQUARE FRAME, ALIGN SHAFT HOLES, TRANSFE' DOWEL HOLES .125Ø AND INSTALL ITEM 29, SPRING PINS

NOTE!

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

1/UNIT

APPLICATION

UNLESS OTHERWISE SPECIFIED

CONTRACT NO.

WESTECH SYSTEMS, INC.

TITLE: ASSEMBLY UPPER ROTATION DRIVE

SIZE: D

DRAWING NUMBER: 1077-08093

REV: A

SCALE: 1:4

WEIGHT

SHEET OF

87000

DO NOT SCALE — WORK TO DIMENSI

ORIGINAL PAGE IS OF POOR QUALITY

ITEM	REQ	PART NO	DESCRIPTION	MATERIAL	MATL SPEC
45	REF		MOTOR-REDUCER 120:1 RATIO 58.33 RPM	317A115-11	GLOBE - TRW 24 VDC
44					
43					
42					
41					
40					
39	1		POLY PAC (SHAFT SEAL)	12500 500	PARKER MATERIAL V4208
38	2		O-RING	2-038	VITON
37	1		O-RING	2-025	VITON
36					
35					
34	1		FLEXIBLE COUPLING (MEGAMITE)	M501-68A	REMBRANDT INC 617-445-8910
33					
32	82 LINKS		LADDER CHAIN (.185 PITCH)	#1A	BOSTON GEAR
31	1		SPROCKET 20 TEETH	CA20 ITEM NO 14794	↓
30	1		SPROCKET 48 TEETH	CBA48 ITEM NO 16874	↓
29	12		SPRING PIN .125 ⌀ x .63	10-125-0625	GROOVE PIN CORP
28	2		SOC. HD CAP SCREW	1/4-20UNC x .63	
27	14		SOC. HD CAP SCREW	#8-32NC x .50	
26	12		SOC. HD CAP SCREW	#6-32 NC x .63	
25	8		SOC. HD CAP SCREW	#4-40 NC x .63	
24					
23	2		FLANGED NYLINER (.500 ID x .22)	8L3½-F	THOMSON INDUSTRIES, INC
22	2		FLANGED NYLINER (.312 ID x .31)	5L5-F	↓
21					

ITEM	REQD	PA
20	REF	1077
19	2	1077-
18		
17		
16		
15		
14	1	1077-
13	1	1077
12	1	983
11	1	1077-
10	2	1077
9	1	1077
8	1	1077-
7	1	1077
6	1	1077-
5	1	1077-
4	1	1077-
3	1	1077-
2	1	1077-
1	X	1077-

1 / UNIT

NEXT ASSY	USED ON

APPLICATION

UNLESS OTHERWISE SP

1. DIM ARE IN INCHES.
2. TOL ON DECIMALS XXX ± XX ±
3. SURFACE ROUGHNESS PER ANSI B46.1
4. INTERPRET DWG PER DOD
5. REMOVE BURRS AND SHA 0.005 TO 0.015
6. MACHINED FILLET RADII 0.
7. DIM LIMITS HELD AFTER P
8. MACHINED DIA'S ON A CO CENTER LINE TO BE CONC WITHIN 0.005 DIA.

MATERIAL

FOLDOUT FRAME

—W... O DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

FOLDOUT FRAME

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20	REF	1077-08091	SLIDER-MODIFIED	B6000 SERIES	VELMEX INC
19	2	1077-08092	KEY	.1875 SQ x .38	KEYSTOCK
18					
17					
16					
15					
14	1	1077-08103	SPACER	3.50Ø x 2.00Ø x 1.69	↑
13	1	1077-08102	SPACER-MOTOR	1.75 Ø x 1.69	AL 6061-T6
12	1	983-81036	MOTOR HOUSING		
11	1	1077-08089	SHAFT-MOTOR	.500Ø x 2.00	DRILL ROD
10	2	1077-08088	SPACER-ROUND	.75Ø x .51Ø x .22	NYLON
9	1	1077-08090	SHAFT	.500Ø x 4.00	DRILL ROD
8	1	1077-08036	ASSY-UPPER CHUCK		
7	1	1077-08087	WASHER-SHIM	.030 x .75Ø x .51Ø	NYLON
6	1	1077-08085	PLATE-BEARING	.25 x 4.00 x 8.00	AL 6061-T6
5	1	1077-08084	PLATE-MOTOR BEARING	.25 x 4.00 x 8.00	↑
4	1	1077-08086	SPACER BAR	.25 x .75 x 3.38	│
3	1	1077-08082	PLATE-BACK	.38 x 6.00 x 8.25	│
2	1	1077-08083	PLATE-SIDE	.25 x 4.00 x 5.50	↓
1	X	1077-08093	ASSY-UPPER ROT. DRIVE		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS XXX = XX = ANGLES ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	WILLY H ZUNKER	20 AUG 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.	[illegible]	
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL

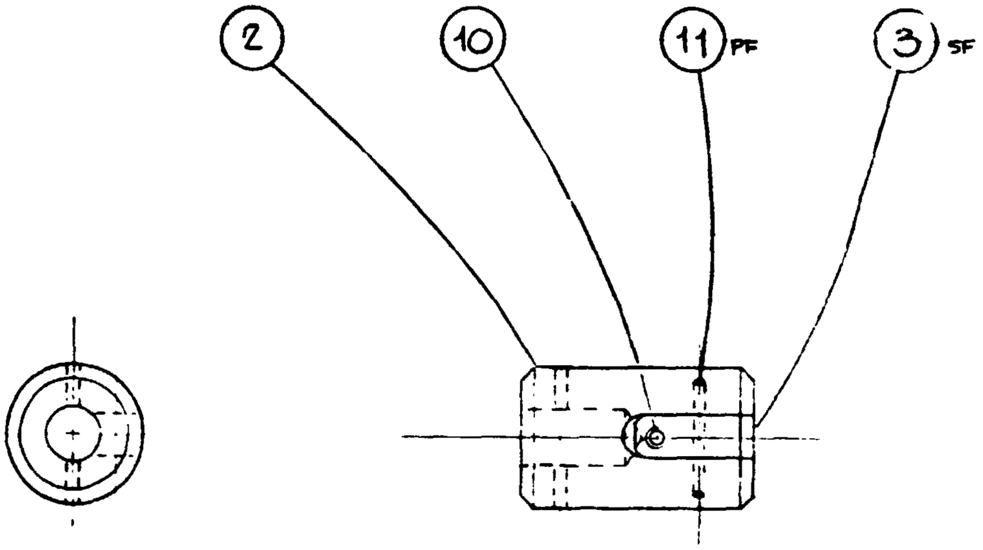
APPROVAL

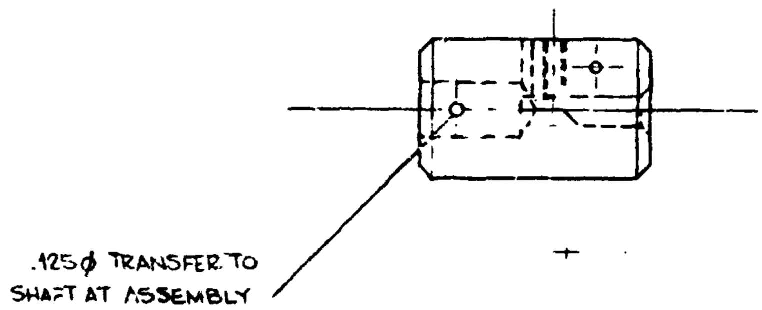
WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

TITLE BILL OF MATERIAL ASSEMBLY UPPER ROTATION DRIVE

SIZE B | FSCM NO. | DRAWING NUMBER 1077-08100 | REV.

SCALE 1:1 | WEIGHT | SHEET OF





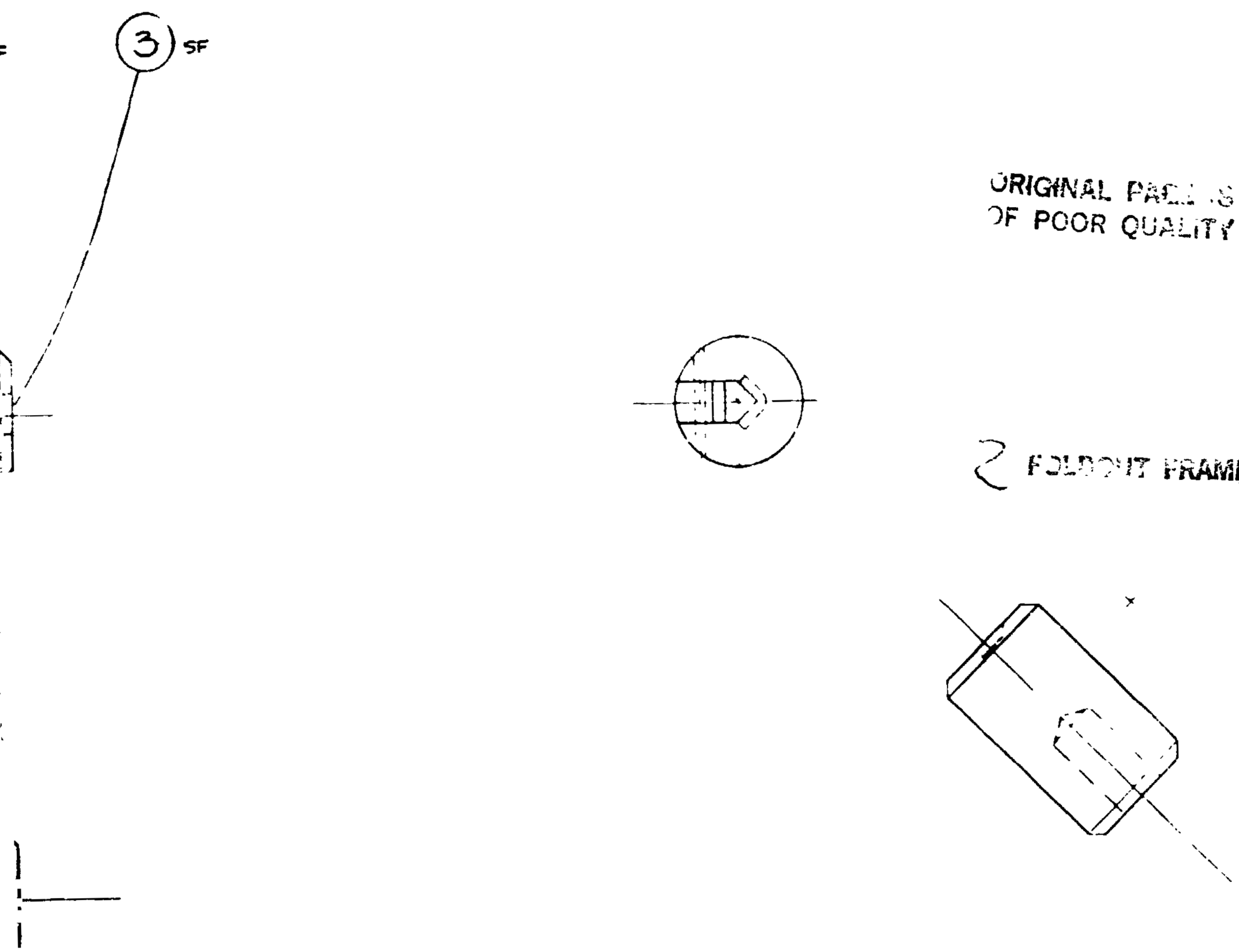
1 /UNIT	
1077-0?040	
NEXT ASSY	USED ON
APPLICATION	

FOLDOUT FRAME

DO NOT SCALE — WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



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2 FOLDOUT FRAME

1077-08043

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

1 / UNIT

NEXT ASSY	USED ON
1077-08040	

APPLICATION

UNLESS OTHERWISE SPECIFIED

MATERIAL

CONTRACT NO

APPROVED / DATE
DRAFTSMAN
CHECKER
PROJECT ENGR
CHIEF ENGR
CHIEF DRAFTSMAN

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA

TITLE
ASSEMBLY
LOWEIZ CHUCK

SIZE C

DRAWING NUMBER 1077-08043

SCALE 1:1

DO NOT SCALE -- WORK TO DIMENSI

ITEM	REQD	
20		
19		
18		
17		
16		
15		
14		
13		
12		
11	1	
10	1	
9		
8		
7		
6		
5		
4		
3	1	107
2	1	107
1	X	107

1 / UNIT	
1077-08110	1077-08077
NEXT ASSY	USED ON

APPLICATION

UNLESS OTHERWISE

1. DIM ARE IN INCHES.
2. TOL ON DECIMALS
   XXX ± XX ±
3. SURFACE ROUGHNESS
   PER ANSI B46.1
4. INTERPRET DWG PER D
5. REMOVE BURRS AND SH
   0.005 TO 0.015.
6. MACHINED FILLET RADI
7. DIM LIMITS HELD AFTER
8. MACHINED DIA'S ON A C
   CENTER LINE TO BE CO
   WITHIN 0.005 DIA.

MATERIAL

FOLDOUT FRAME

— WORK TO DIMENSIONS GIVEN

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

ORIGINAL PAGE IS
OF POOR QUALITY

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20					
19					
18					
17					
16					
15					
14					
13					
12					
11	1		SPRING PIN	SP-125-0875	GROOV-PIN CORP KENNEDY SALES
10	1		BALL PLUNGER #10-32 NF	SSBH-52	VLIER ENGINEERING
9					
8					
7					
6					
5					
4					
3	1	1077-08039	BAR	.38×.50×1.13	CRES 304
2	1	1077-08044	CHUCK BODY	1.25 ⌀ × 2.13	
1	X	1077-08043	ASSEMBLY-LOWER CHUCK		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
1. DIM ARE IN INCHES.
2. TOL ON DECIMALS XXX ± XX ± ANGLES ±
3. SURFACE ROUGHNESS PER ANSI B46.1 ✓
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
6. MACHINED FILLET RADII 0.030 TO 0.015.
7. DIM LIMITS HELD AFTER PLATING.
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	WILLY H ZUNKER	2 OCT 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.	[illegible]	10-3-84
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL BG WB

APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

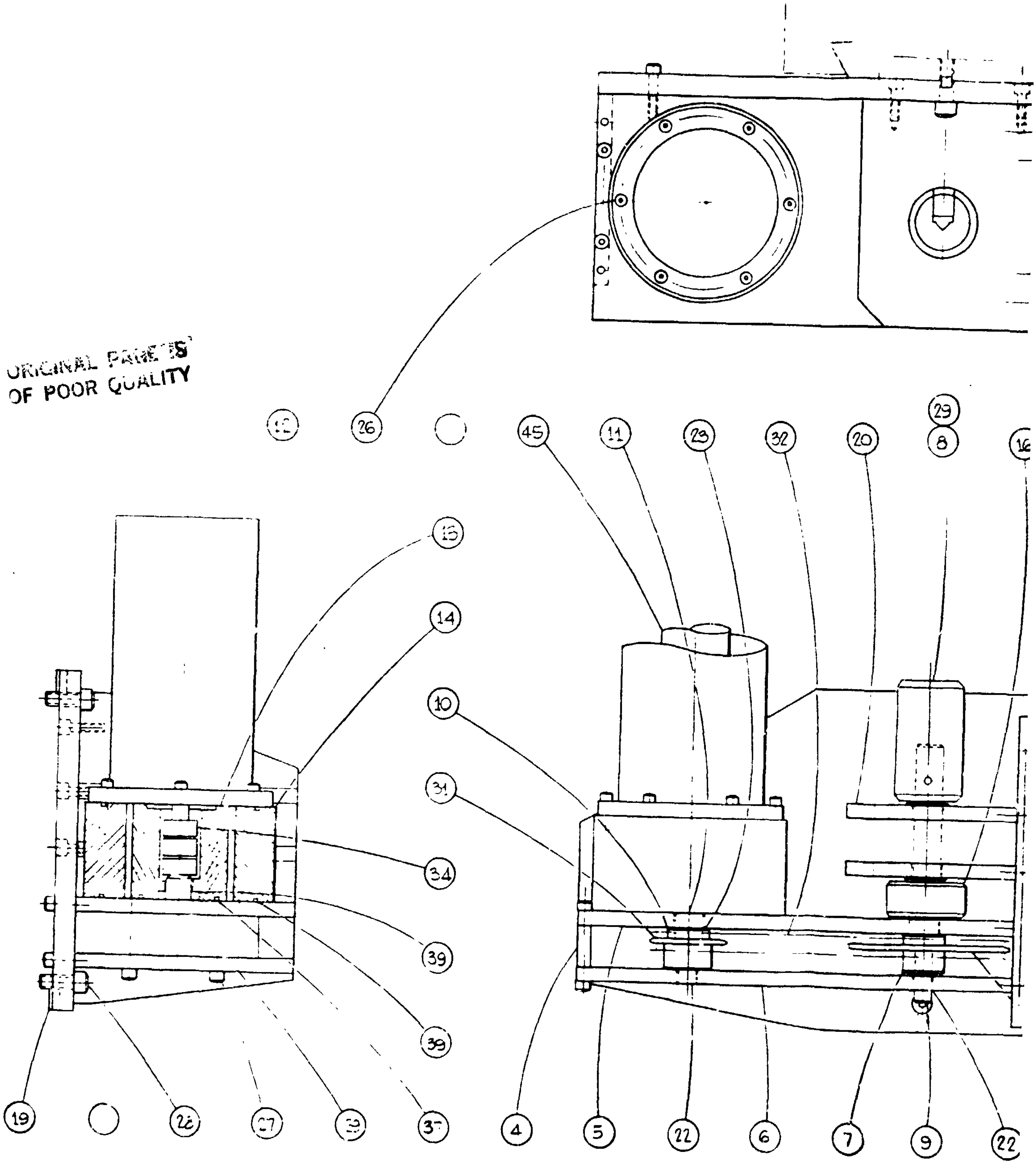
TITLE BILL OF MATERIAL ASSEMBLY LOWER CHUCK

SIZE	FSCM NO.	DRAWING NUMBER	REV.
B		1077-08040	

SCALE 4/1 WEIGHT SHEET OF

661 FOLDOUT FRAME

2

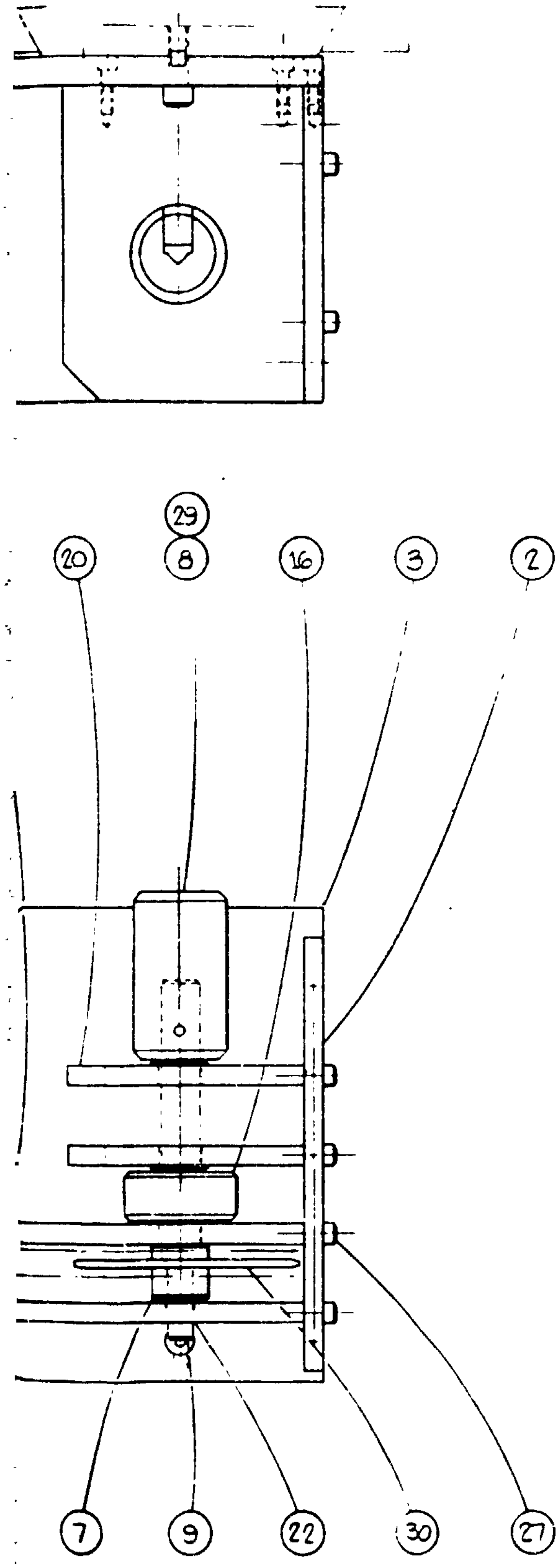


FOLDOUT FRAME

DO NOT SCALE — WORK TO DIMENSIONS GIVEN

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



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2 FOLDOUT FRAME

1 BEFORE FINAL ASSEMBLY SQUARE FRAME ALIGN SHAFT HOLES, TRANSFER DOWEL HOLES AND INSTALL ITEM 29 (SPRING PINS).

NOTE:

ITEM	REQD	PART NO	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

1/UNIT

APPLICATION

WESTECH SYSTEMS, INC.

ASSEMBLY
ER ROTATION DRIVE

D 1077-08077

88594

DO NOT SCALE — WORK TO DIMENSI

ITEM	REQ	PART NO	DESCRIPTION	MATERIAL	MATL SPEC
45	REF		MOTOR-REDUCER 120:1 RATIO 58.33 RPM 24VDC	317A115-11	GLOBE-TRW
44	REF	1077-08091	SLIDER-MODIFIED	B6000 SERIES	VELMEX INC
43					
42					
41	1		MAGNET-6 POLE SALIENT RADIAL	SRP-964	BUNTING MAGNETICS 316-284-2020
40					
39	1		POLY PAC (SHAFT SEAL)	12500500	PARKER MATERIAL V4208
38	2		O-RING	2-038	VITON
37	1		O-RING	2-025	VITON
36					
35					
34	1		FLEXIBLE COUPLING (MEGA MITE)	M501-68 A	REMBRANDT INC. 617-446-8910
33					
32	32 LINKS.		LADDER CHAIN (.125" PITCH)	#1A CRES	BOSTON GEAR
31	1		SPROCKET 20 TEETH	CA20 ITEM NO 14794	
30	1		SPROCKET 48 TEETH	CBA48 ITEM NO 16874	
29	2		SPRING PIN .125Φ × .63	SP-125-0625	GROOVE PIN CORP.
28	2		SOC HD CAP SCREW	1/4-20 UNC × .75	
27	23		SOC HD CAP SCREW	#8-32 NC × .50	
26	12		SOC HD CAP SCREW	#6-32 NC × .63	
25	8		SOC HD CAP SCREW	#4-40 NC × .63	
24	1		BUTTON HD CAP SCREW	1/4-20 UNC × .50	
23	4		FLANGED NYLINER	8L 3 1/2-F	THOMSON INDUSTRIES INC.
22	2		FLANGED NYLINER	5L5-F	" "
21	2	1077-08092	KEY	.1015 SQ × .38	KEY STOCK

ITEM	REQD	
20	2	107
19		
18	1	107
17	1	107
16	1	107
15	1	107
14	1	107
13	1	107
12	1	107
11	1	107
10	2	107
9	1	107
8	1	107
7	1	107
6	1	107
5	1	107
4	1	107
3	1	107
2	1	107
1	X	10

1/UNIT

UNLESS OTHERWISE
1. DIM ARE IN INCHES.
2. TOLERANCE ON: DECIMALS
XXX ± XX
3. SURFACE ROUGHNESS PER ANSI B46.1
4. INTERPRET DWG PER
5. REMOVE BURRS AND 0.005 TO 0.015.
6. MACHINED FILLET RA
7. DIM LIMITS HELD AF
8. MACHINED DIA'S ON A CENTER LINE TO BE WITHIN 0.005 DIA.

MATERIAL

ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME

NEXT ASSY	USED ON

APPLICATION

ZONE	LTR	DESCRIPTION	DATE	APPROVED

ORIGINAL PAGE IS
OF POOR QUALITY

2 FOLDOUT FRAME

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC
20	2	1077-08095	PLATE-CHUCK BEARING	.25×4.00×3.15	AL 6061-T6
19					
18	1	1077-08098	CUP-CLUTCH	1.500ϕ×.63	CRS 1018
17	1	1077-08097	SHAFT-DRIVEN	.500ϕ×2.55	DRILL ROD
16	1	1077-08079	ASSEMBLY-CUP SHAFT		
15	1	1077-08096	SHAFT-DRIVER	.500ϕ×1.75	DRILL ROD
14	1	1077-08103	SPACER	3.500ϕ×2.00ϕ×1.69	AL 6061-T6
13	1	1077-08102	SPACER-MOTOR	1.75ϕ×1.69	
12	1	1077-08101	MOTOR HOUSING		
11	1	1077-08089	SHAFT-MOTOR	.500ϕ×2.00	DRILL ROD
10	2	1077-08088	SPACER-ROUND	.75ϕ×.51ϕ×.22	NYLON
9	1	1077-08078	ASSY-MAGNET SHAFT		
8	1	1077-08040	ASSY-LOWER CHUCK		
7	1	1077-08087	WASHER-SHIM	.040×.75ϕ×.51ϕ	NYLON
6	1	1077-08085	PLATE-BEARING	.25×4.00×8.13	AL 6061-T6
5	1	1077-08084	PLATE-MOTOR BEARING	.25×4.00×8.13	
4	1	1077-08086	SPACER BAR	.25×.75×3.38	
3	1	1077-08094	PLATE-BACK	.38×6.00×8.25	
2	1	1077-08099	PLATE-SIDE	.25×4.00×5.50	
1	X	1077-08077	ASSY-LOWER ROT. DR. CLUTCH'D		

PARTS LIST

UNLESS OTHERWISE SPECIFIED
1. DIM ARE IN INCHES
2. TOLERANCE ON: DECIMALS ANGLES
XXX ± XX ± ±
3. SURFACE ROUGHNESS PER ANSI 46.1
4. INTERPRET DWG PER DOD-STD-100
5. REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015
6. MACHINED FILLET RADII 0.030 TO 0.015
7. DIM LIMITS HELD AFTER PLATING
8. MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.035 DIA

MATERIAL

CONTRACT NO.

APPROVED		DATE
DRAFTSMAN	WILLY H ZUNKER	2 OCT 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR.	[illegible]	10-2-84
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL BA 10/2

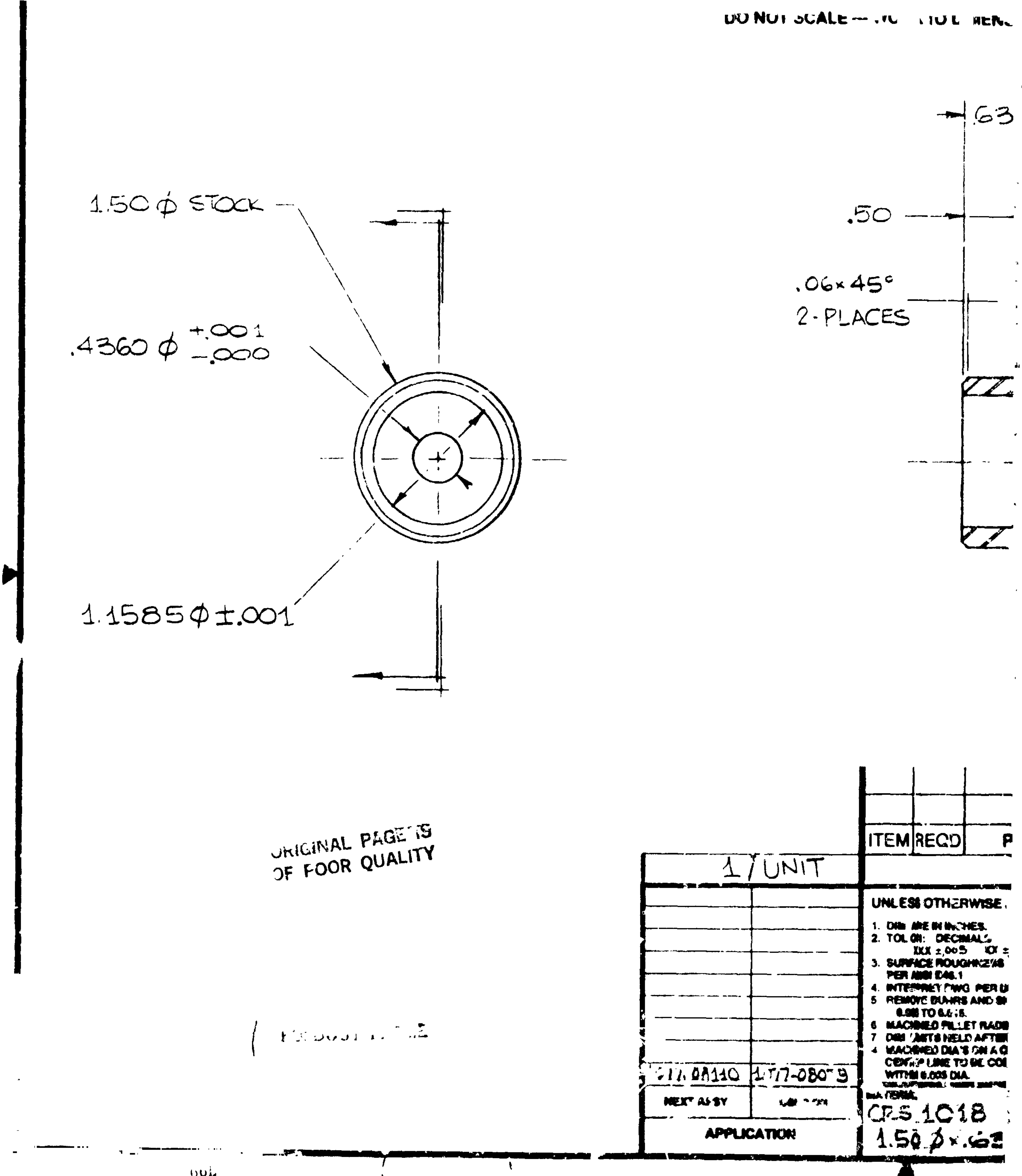
APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

TITLE BILL OF MATERIAL ASSEMBLY LOWER ROTATION DRIVE, CLUTCHED

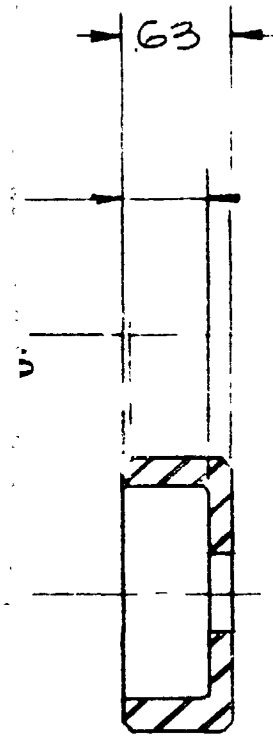
SIZE	FSCM NO.	DRAWING NUMBER	REV.
B		1077-08110	

SCALE 4/7 WEIGHT SHEET OF


DO NOT SCALE
1.50 ϕ STOCK
.4360 ϕ +.001 -.000
1.1585 ϕ ±.001
.63
.50
.06×45°
2-PLACES
ITEM
REQD
1/UNIT
UNLESS OTHERWISE
1. DIM ARE IN INCHES.
2. TOL ON: DECIMALS
3. SURFACE ROUGHNESS
PER ANSI B46.1
4. INTERPRET DWG PER
5. REMOVE BURRS AND
6. MACHINED FILLET RADII
7. DIM LIMITS HELD AFTER
8. MACHINED DIA'S ON A C
CENTER LINE TO BE CO
WITHIN 0.005 DIA.
NEXT ASSY
APPLICATION
MATERIAL
CRS 1018
1.50 ϕ × .63

TO DIMENSIONS GIVEN

ZONE	LTR	DESCRIPTION	DATE	APPROVED
		REVISIONS		



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OF POOR QUALITY

2

C-2

ITEM	REQD	PART NO.	DESCRIPTION	MATERIAL	MATL SPEC

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOL ON: DECIMALS XXX ±.005 XX ±.02 ANGLES ±0°-15'
SURFACE ROUGHNESS 32 ✓
PER ANSI B46.1
INTERPRET DWG PER DOD-STD-100
REMOVE BURRS AND SHARP EDGES 0.005 TO 0.015.
MACHINED FILLET RADII 0.030 TO 0.015
LIMITS HELD AFTER PLATING.
MACHINED DIA'S ON A COMMON CENTER LINE TO BE CONCENTRIC WITHIN 0.005 DIA.

MATERIAL
CRS 1018
.50 ⌀ × .63

CONTRACT NO. ______

APPROVED		DATE
DRAFTSMAN	WILLY R. ZUNKER	28 SEPT 1984
CHECKER		
DESIGN ANALYSIS		
PROJECT ENGR	[illegible]	10-3-84
CHIEF ENGR.		
CHIEF DRAFTSMAN		

APPROVAL BC WL

APPROVAL

WESTECH SYSTEMS, INC.
PHOENIX, ARIZONA 85040

TITLE
CUP - CLUTCH

SIZE	FSCM NO.	DRAWING NUMBER	REV.
B		1077-08098	

SCALE	WEIGHT	SHEET	OF
1:1	.31#		

(23) Flanged nyliner*

(30) Sprocket 48 tooth*

(31) Sprocket 20 tooth*

(32) Ladder chain*

(41) Magnet, six pole. Provides the magnetic field forces that rotate the chuck.

C. ELECTRONIC CONTROL

INTRODUCTION

The design effort of the previous contract was based on the premise that only one EAC would be available for the experiment. In this situation minimum space would be available for electronics, thus placing a premium on abbreviated function. Addition of the second EAC will allow us to re-define the functions and make possible a more sophisticated approach.

1. Computer System

The use of two EAC units allows some re-consideration of the electronics package. Specifically, the volume of space available will undoubtedly allow a more sophisticated computer system than was originally planned. Use of high level languages such as Basic, Fortran, Pascal, etc., give tremendous increase in programming productivity, but tend to be difficult or even impossible to use in a non-disc environment. With the added space available, we can make use of more memory arranged as a pseudo-disc in both ROM and EEPROM to provide an environment suitable for the use of these languages. More memory also means more space available for data storage, in the form of either EEPROM or BUBBLE memory.

2. Motor Controls

The translation and rotation motor controls currently used are closed loop velocity servos with analog feedback. These controls will be replaced by a system similar to the Westech Digital Motor Control developed for commercial use. These systems are phase locked to a crystal time base and are limited in long term accuracy only by the crystal.

3. Furnace Heat Control

The heater control will be a Pulse Width Modulated switching type that will allow high accuracy control, and also be highly efficient. Particular emphasis will be placed on E.M.I. and peak current loads.

Heater power is dependent on atmosphere; the lower the pressure, the lower the required power. Use of gas such as Argon increases the required power. Continued ground based experiments will refine previous data to establish the appropriate power for the desired atmosphere and material.

D. MICROGRAVITY FLOAT ZONING TECHNICAL SPECIFICATIONS

The following specifications have been developed for float zone growth of silicon and silicon-germanium alloys as well as other III-V materials and metals. The flexibility inherent in the design of this zoner allows parameter changing to accommodate a wide range of growth conditions. Table 5 lists particular specifications aimed at silicon zoning.

TABLE 5.

Crystal diameter	up to 7mm
Crystal length	
Overall	41 cm.
Zoned portion	15 cm.
Axial growth speeds:	
Furnace movement, slow	0.01 to 1.5mm/min. (option)
Furnace movement, fast	0.1 to 6.5mm/min.
Seed movement	1 to 50mm/min.
Rotation rates	0.1 to 20 RPM
Maximum growth temperature	1500 deg. cent.
Maximum furnace power	200 watts, 24vdc
Zoning atmosphere	Argon, 0.1 torr
Total power consumption	465 watts
Allowed power consumption	470 watts

E. MICROGRAVITY ZONER HARDWARE SPECIFICATIONS

In addition to the Float Zoning specifications presented in the previous section, the zoner hardware and its operation will be further specified. The previous program designed and built prototype hardware that gave basis for this effort, and this experience provides the background for this new specification.

1. General Description

The flight prototype is as shown in Figure 17. To lend some perspective to the relative state of this model compared to the original, note that in the original unit the addition of a sample holder would have required either increasing the height or folding the top transport down. In the new unit, the sample holder is already provided for, and needs only to be built and attached.

2. Physical Dimensions

The thin rod zoner was conceived as a very close representation of the flight model, so it was designed to meet dimension specifications as presented in MSL Users Handbook paragraph 2.1.2.4. Weight will apparently not be a major problem as the zoner currently weighs 75 pounds, well under the 275 pound limit of paragraph 2.1.2.4, or the 680 pound limit of paragraph 2.1.3. Addition of the sample holder and other hardware will add 50 pounds (estimated) to the current weight. The center of gravity of the zoner was measured and found to be 13 inches in the vertical axis.

3. Power Budget

The power requirements are:

Overall power	470 watts
Heater, including control	220 watts
Electronic controls	170 watts
Conversion losses	75 watts

4. Furnace and EAC Temperatures

A zoning temperature of up to 1500°C will be attained within the furnace, but use of highly efficient insulation techniques keep the temperature of external furnace parts down to 30°C or less, even with no coolant flowing. We do not anticipate a significant heat load and foresee the probability of using insulation of some sort to maintain the internal termperatures at 25°C, especially the EAC that houses the electronics and control package.

5. Vacuum and Atmospheric Considerations

The experiments will be conducted in Argon at 0.1 torr. This vacuum can be achievable by venting to space. We may find it desirable to use a filter on the vacuum line. If higher vacuum is found necessary, an ion pump will be mounted.

6. Sequence Programming

The entire sequence of the experiments will be programmed into the on board computer, including all zoner movements, heat cycles, atmosphere changes, data collection and storing, sample changing, time lining, and fault and error detection and correction. For ease of program design, a personal computer will be used to develop algorithms, and to control the operation and data collection on the ground based experiments.

7. Safety

The Microgravity Thin Rod Zoner will be designed to conform to NASA NHB1700.7A. The design and the hardware will be reviewed to eliminate hazardous situations. Automatic safety devices will be used to reduce hazards to specified levels. All hazards will be contained within the confines of the EAC's, and there will be no hazard to the shuttle or its crew, nor to other experiments.

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